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Lab Every Day!! Lab Every Day?? *&%#ing Lab Every Day!? Examining Student Attitudes in a Core Engineering Course Using Hands-on Learning Every Day of Class

Dr. Erin A. Henslee, Wake Forest University

Dr. Erin Henslee is a Founding Faculty and Assistant Professor of Engineering at Wake Forest University. Her research spans biomedical engineering, e-sports, and STEM education. Prior to joining Wake Forest she was a Researcher Development Officer at the University of Surrey where she supported Early Career Researchers. She received her BS degrees in Engineering Science and Mechanics and Mathematics from Virginia Tech, her MS degree in Biomedical Engineering from the joint program between Virginia Tech and Wake Forest University, and her PhD in Biomedical Engineering from the University of Surrey.

Kyle Luthy
William N. Crowe
Lindsey J. Gray, Wake Forest University

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Abstract

The author's Control Systems and Instrumentation course is a four credit, core course combining topics traditionally taught across several courses including electrical theory, instrumentation, signal processing, and controls. To meet this challenge, the authors took a student centered approach to the course design as well as active learning pedagogy. From this approach the course was structured where students work through theory and hands-on labs each class period. This infused basic electrical theory and instrumentation with Arduino-based sensors and control algorithms, and has allowed alignment of every day of the course with multiple student learning outcomes. In this work the authors present student outcomes of the approach. These are informed by methods of formative and summative assessment as well as evidence of achievement through regular informal student feedback, course evaluations, observations, and focus groups.

The assessment strategy has included formative assessment of daily concept check points. Every week the next week's activities are adjusted to ensure the material stayed within the cohort's zone of proximal development, towards mastery of the content. Projects were designed to reinforce learning outcomes achieved at check points throughout the semester. Summative assessment included project deliverables, homework based on theoretical problem solving, as well as a midterm and final that included a take-home portion, a partnered practical lab-based exercise, and a problem solving section.

The primary challenges faced included how to facilitate better connections students made across the content and how to assist students in the cognitive shifts necessary in a fast-paced and pedagogically very different environment than they are used to. The authors have worked towards this by creating more connection opportunities through improved theoretical content, alignment of reading quizzes and structured outside of class work. Mid-term and final course evaluations as well as facilitated focus groups have been conducted for three semesters. Three semesters of classroom observations made through the Classroom Observation Protocol for Undergraduate STEM (COPUS) have also been completed. From these, mixed results with regards to student attitudes towards the hands-on nature of the course have been reported. While most students have enjoyed the hands-on work, less were convinced of the connections they were making to the theory. Some students went so far as to request more lectures and less lab time. Student attitudes towards working with their partner and peer-to-peer learning were positive across cohorts and semesters. In light of this the authors describe methods of scaffolded opportunities for independent as well as peer-to-peer learning.

While student preferences varied, data is also presented on student behavior and achievement. Class attendance remained over 90% throughout all three semesters (including the COVID Spring 2020 semester). Student feedback has indicated a sense of obligation to their lab partners and perceived value of the in-class activities to be the primary motivators of attendance. Further, data on student achievement of summative assessments across topics has been summarized. This data suggests that topics students spent more hands-on time with resulted in better performance.

Introduction

According to the Bureau of Labor and Statistics, the average person has 10 jobs by the age of 40 [1]. This can be seen in Engineering and also reflected in what Engineering graduates are doing five and ten years post degree[2], [3] . Further, nearly 25% of the Best Performing CEOs started with a B.S. in Engineering [4]. Industry continues to ask for more well-rounded competencies of new Engineers. The T-shaped engineer combines a depth of engineering technical knowledge with broad knowledge across domains such as business, communications, entrepreneurship, and ethics [2], [5]. Fostering 21st century skills ensures Engineers are equipped to tackle the Grand Challenges put forth by the National Academy of Engineering, the NSF's Big Ideas, or *The Engineer of 2020*[2], [6].

Against this backdrop, the authors' new B.S. in Engineering program was established. The curriculum is grounded in the principle that fundamental engineering concepts span across disciplines, connect, and build upon one another in engineering design. Further, for these fundamentals to be put into practice in meaningful ways critical analysis, stakeholder engagement, and a reflective, iterative process are crucial skills for students to develop in our courses. An outcome from this paradigm is a four-credit course structure in which each year has two "core" courses that cover a subset of engineering fundamentals increasing in complexity as the students progress. One of the primary challenges the authors faced at the course design stage is how to condense three to four traditional engineering courses into one, cohesive four-credit course. For students, the challenge of these courses is not only the amount of content, but also how the content is introduced and reinforced. As interdisciplinary and transdisciplinary approaches become more common place, a recent review cited the challenges in defining clear learning goals and assessments [7]. A focus on teamwork and interpersonal skills within project-based learning was found to be effective methods in current practices.

This paper will elaborate on the course design process and recent outcomes of the course design in the context of the authors' new Control Systems and Instrumentation course. The authors will outline the student-centered learning approach taken to combine traditionally 3-4 courses into one, 4-credit course. This resulted in a novel, lab-every-day course design in which lecture and lab were combined (labture) as a way to leverage hands-on learning with theoretical content (i.e. teach students how to use Engineering instruments while learning the theory behind those instruments). The authors will describe and present student work on exemplar labtures and projects as well as their formative and summative assessment strategies. Further, this paper will demonstrate the benefits of the labture approach to student outcomes including performance measures, course feedback, and classroom observations.

Purpose and Context

The purpose of this work is to demonstrate the effectiveness of a "labture" model, in which lab and lecture are combined to maximize course efficiencies and provide students with the knowledge, skills, and attitudes typically addressed across multiple courses. Active learning (AL) has been linked to improve self-efficacy and the recruitment and retention of underrepresented students in STEM fields, including in graduate research degree pathways [8], [9]. However, current work has also shown that pedagogical interventions must be intentionally designed or outcomes may not be equitable across student groups [10]–[12]. With this in mind, the authors will also present on their reflective practice and strategies for inclusive AL practice.

The course is at Wake Forest University, a medium-sized, Liberal Arts University in a general Engineering Department. It is a Junior-level, core class of four credits. It meets three times a week for 1 hr and 50 min each session. The classroom space is a teaching lab, accommodating 12 pairs of students, each pair at a bench (Figure 1). The design of the room was intentional to support aspects of the pedagogical approach (described subsequently). The pods of tables accommodate four groups of student pairs, essential to the collaborative goals of the labture approach. The authors designed the classroom space to optimize the ability for instructors to access each group, student line-of-sight to a long whiteboard space, and visible storage to encourage students to seek equipment and materials required. Each bench is equipped with standard instrumentation including power supply, oscilloscope, function generator, and digital multi-meter. The classroom is also equipped with soldering stations, basic tools, lab sink, other measurement instruments, as well as lockable storage. Each student receives a take-home kit, which includes an Arduino kit, circuit components, wire strippers, a multi-meter, and other project materials.

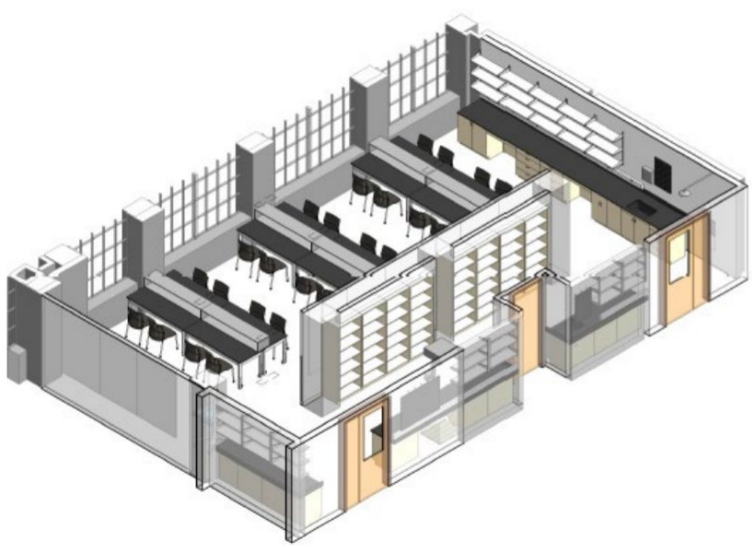

Figure 1: The teaching lab was designed to support collaborative work and the ability for instructors to observe all students. As a permanent lab and teaching space, the room had to be able to support spontaneous lectures, board work, and demonstrations if the students required whole-class assistance.

Importantly, pre- or co-requisites of the course include Physics 1, Chemistry 1, Multivariable Calculus, Linear Algebra and Differential Equations as well as the Freshman and Sophomore Engineering courses. Not required are Physics 2 (essentials of electricity, magnetism, optics) or any pre-requisite programming experience. This is an important feature in the department course structure, as the Engineering curriculum was designed to be as inclusive as possible. Subsequently, the pre-requisite structure versus what could be covered in the core curricula was carefully considered. In the context of the authors' course, this meant the course had to accommodate students with no programming background or basic electrical theory.

Student Learning Approach and Course Development

In the Summer of 2019 the authors participated in their Center for Advancement of Teaching's summer course (re)design program to design their Control Systems and Instrumentation course. During this program, the authors worked through the book, *Building a Pathway for Student Learning* [13]. Before this program, the authors approached the course design as "how can we possibly consolidate all these topics to one course?" The course changed the authors' narrative to "what do our students look like after they have completed our course? What can they *do* that they could not before taking our course?" From this crucial change in perspective, the authors began to work backwards from a final project, build an electrocardiogram (ECG), and other course goals, deconstructing the learning outcomes necessary to achieving these (Figure 2).

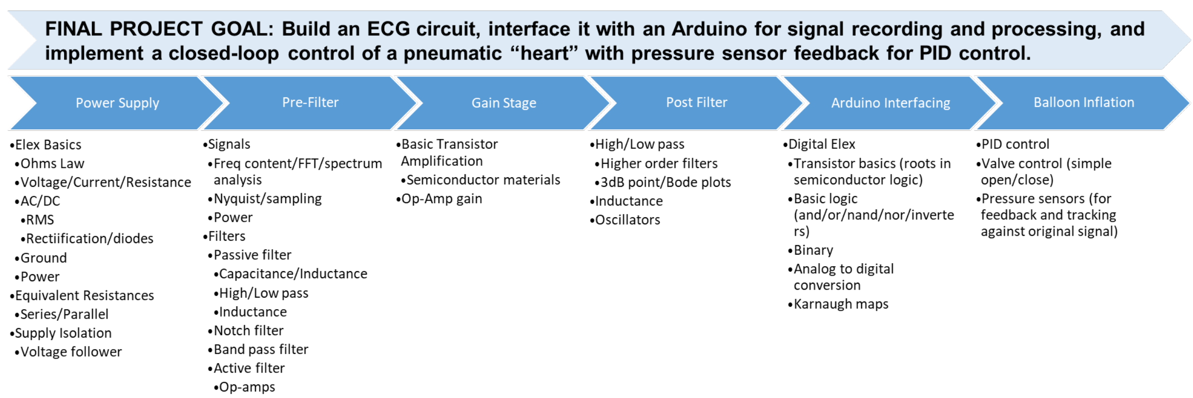

Figure 2: The course design focused on topics to support the students' abilities to complete a final project on ECG signal gathering, processing and implementing a control algorithm.

From this approach, the authors created the course structure where students work through theory and hands-on learning, completing concept checkpoints throughout each class. Working through the development activities in *Building a Pathway*, the authors created posters for each of the course modules (Figure 3).

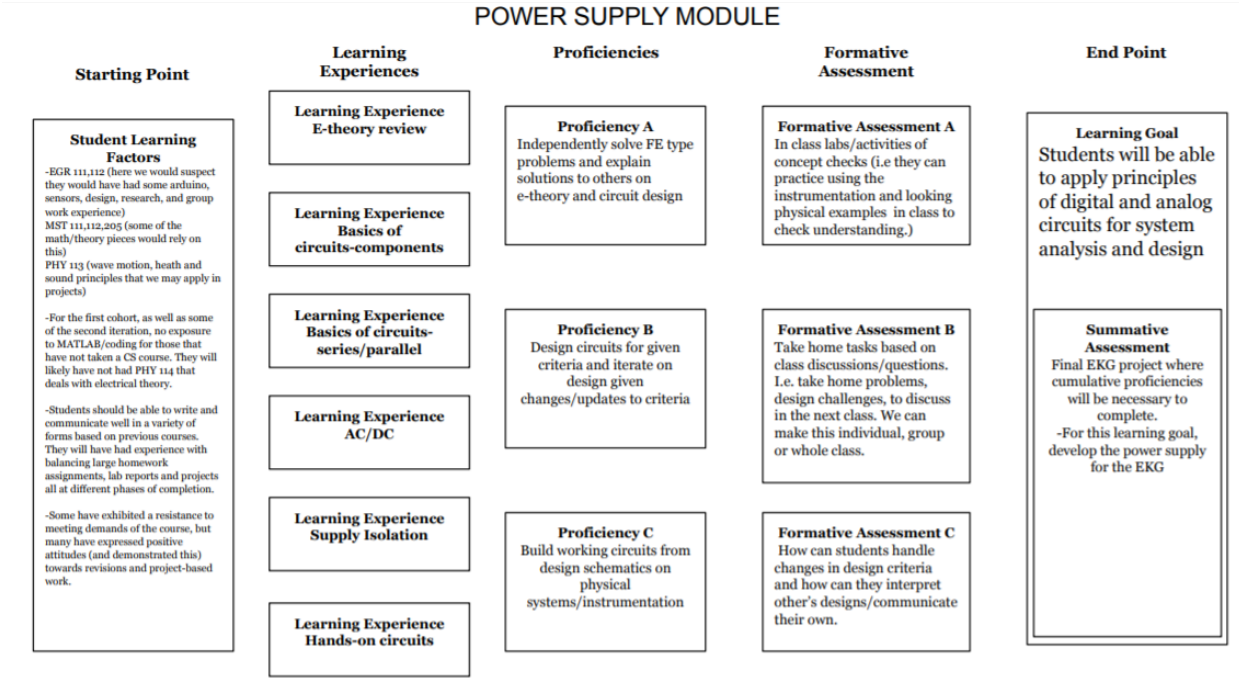

Figure 3: An example Module poster during the course design process following the book activities in Building a Pathway for Student Learning[13].

Labture

The labture approach was an adaptation of the Problem Solving Studio (PSS) [14]. The PSS approach is aimed at improving students' conceptual understanding of material by pairing students to solve complex problems with limited structure, keeping them in a constructive mode of learning. Under this framework, instructors facilitate learning by creating an environment where the complexity of problems is tailored to students in real-time to keep them within the zone of proximal development [15]. The labture model liberally defined "problem solving" by extending beyond calculation problems, including conceptual problems such as "why does the order of the capacitor and resistor dictate what type of filter we have?" This provided a more open-ended, conceptual experience when compared to a laboratory course, as well as gave instructors an opportunity to cater to the various levels of pre-requisite knowledge the students bring each semester.

While the labture experience took liberties with the PSS model, the key fundamental aspects of PSS were maintained. First, students work in the same teams of two during the semester to complete labture tasks, working at a pod of tables with another team of two. Second, the teams all work in a public, shared labture space that includes equipment, whiteboards, projection screens, and peripheral supplies (such as solder station, equipment station etc.). Instructors and TAs circulate the room during the working session of the labture, providing students with real-time feedback. This real-time observation allows tailored adjustments of complexity for each team, providing scaffolding appropriate to balance challenge for the individual with what could be completed by the team. Finally, another tenant of the PSS used in this model is the use of continuous student feedback (described subsequently).

The labture approach follows a similar model every day of class (Figure 4). Students will have some pre-work (taking 0.5-1hr to complete) leveraging a flipped classroom approach. The beginning of each class starts with some instruction often including working through complex theory or calculations. Students are then given some context to the activity. With their partner, they then follow a labture guide at their own pace, while instructors circulate the room to support preliminary discussions with each group. Typically, the whole class will need to come together 2-3 times during the working period to collectively work through topics such as equipment questions, complex calculations, errors in code/equipment. Since the aim of the PSS approach is to provide students a safe space for failure (i.e. the PSS session is not graded), the authors wished to preserve this aspect of the PSS while contending with challenges described in the iterative development. The current state of the Labture assessment is a bulleted list of deliverables often graded for completion, with feedback provided on incorrect work.

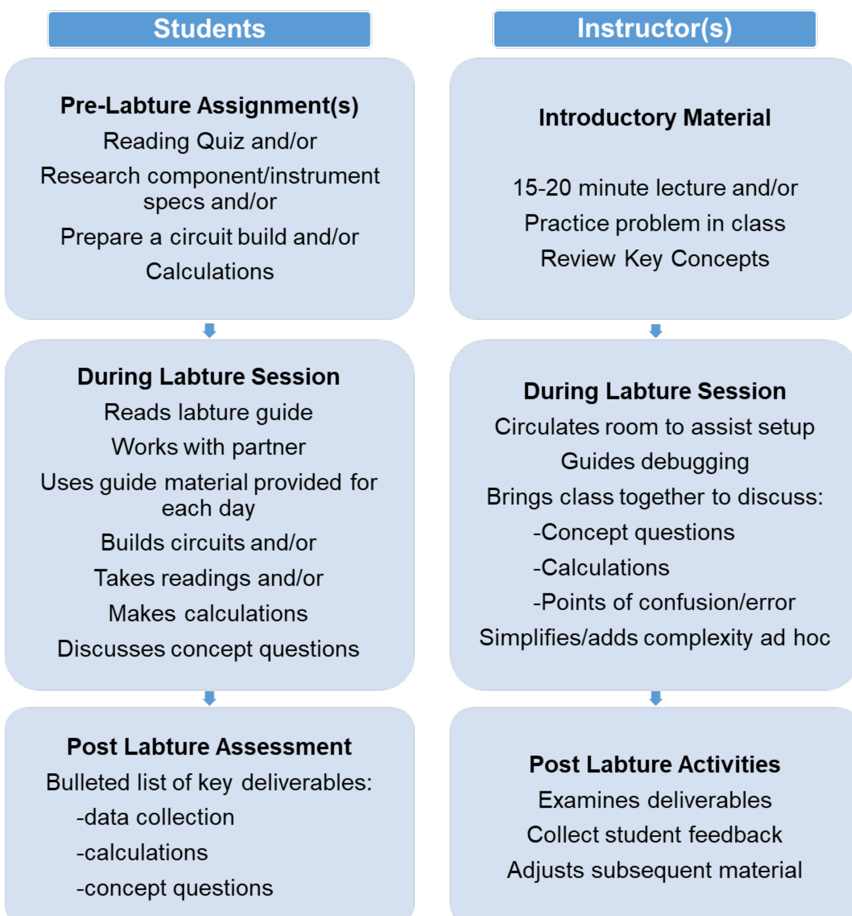

Figure 4: The typical workflow of a labture for the students and instructors. Class periods are 1 hr and 50 min. Students complete some pre-labture reading/work prior to each class. Instructors open class with brief lecture overview and any clarifications for the hands-on portion. At least 1 hour is dedicated to the hands-on portion of the lectures. Some labtures extend beyond one class period to support multiple learning objectives or extensive data

collection. Post labture includes student submission of key deliverables and instructor collection of student reflections or reviews.

Collecting student feedback

The authors have students reflect at the end of each module. This includes a team reflection as well as a personal reflection on character virtue development [16]. The authors also conduct a midterm, externally facilitated, course evaluation that consists of two parts. Part one is an individual start-stop-continue (SSC) questionnaire. Part 2 is a small group discussion reflecting on the questionnaire. The facilitator asks the group to select 2-3 ideas that represent a group consensus for that question, then repeats this for the others. A comprehensive final course evaluation is given during the last week of the course [17].

Iterative Course Design

Fall 2019

The focus on the first iteration was to trial the use of the labture in the PSS approach, so like a PSS, not something completed for a grade. The course was small, consisting of 12 students with 2 instructors and 2 teaching assistants. This low student to teacher ratio provided students with easy access to an instructor during the labture. Likewise, the instruction team could easily monitor the progress of the students. These daily checkpoints were used as formative assessment for students to check their own understanding and give instructors an indication of individual student progress with the material. Every week the next week's labture was designed to ensure the material remained within the cohort's zone of proximal development, towards mastery of the content. Three projects aimed to assess learning outcomes achieved at checkpoints through the semester were also completed. Summative assessment included these project deliverables, homework based on theoretical problem solving, as well as a midterm and final exam that included a take-home portion, a practical lab-based exercise, as well as a problem solving section.

In general, student feedback on the course was positive. When surveyed (See Survey Questions), 100% (n=12) agreed that the in class activities were valuable to their learning. Student comments included, "*I liked that the class was hands on. Having lecture and lab within the same class period helped to cement class topics because we were required to demonstrate our understanding. Having to do so also helped to work out any kinks in understanding right away. It was also very helpful having two TAs that could circle around the room. They often had more experience with the builds and different ways of explaining topics that helped increase my understanding of the material."* Many students cited the availability of the TAs and instructors as the primary resources they used to support their learning.

When asked to rate how valuable course artifacts were for their learning, 100% of students agreed in-class activities, out of class assignments, projects, and labture guides were valuable. Further, when negotiations of final percentages of the three-part final exam and the final project took place (totaling 30% of their final grade). Students opted to have it all equally split as they noted they felt equally confident in their abilities to complete all of the components.

The final class average was an 85% (B) with a high of 94% (A) and low of 78% (C+). This average reflects an optional mid-term resubmission of one problem, and optional problem set to replace the lowest grade. The breakdown of the larger assessments of the course are given in Table 1. Of note, was the large spread between low and high grades on exams (which were individually assessed).

Table 1: Assessment summary of Fall 2020 semester

Assessment	Average (n=12)	Low	High
Problem Sets	77.90%	34%	100%
Project 1	84.20%	70%	97.50%
Project 2	86.70%	76.70%	100%
Project 3	85.40%	78%	89%
ECG Project	89.70%	79%	100%
Midterm Practical	70%	38%	90%
Midterm Theory	89.70%	78.70%	100%
Final Practical	83.60%	72%	96%
Final Theory	74.30%	40%	90%
Final Take-Home	73%	38%	93%

Through the formative assessments, it became apparent that some student's performance on individual activities demonstrated too much reliance on their lab partner or project group members. Students often would not finish the labtures beyond what the instructor guided them to do in class. Student comments suggested that they did not realize they had to complete the labtures since they did not have to turn anything in. This meant they were likely missing learning goals intended of each labture. The survey also included students' own assessment of this. When asked what *they* could have done to support their learning they noted, "Taken more notes, read the documents given to us."

Reflecting on this first iteration, from the student perspective, this labture model added an initially overlooked layer of complexity to the course; students have to cognitively shift from examining the theory to applying the theory within the span of a two-hour class period three times a week, often with new topics that built upon one another each day. Further, students often had to make this shift before they felt they had a solid grasp on the theory. One student comment highlighting this:

> *"I suggest explaining the lecture material a little bit more …they were gone over too quickly and it was hard to grasp some of the things that were taught."*

When asked what the instructor could have done better to improve their learning, one student noted "lecture more."

In interviewing students specifically about the pace and labture approach, it was evident students were assuming a traditional lab model. They expected to be presented with all of the theory and topical learning *prior* to completing anything hands on. Further, they were not connecting previous knowledge to the new concepts, treating each labture as isolated learning experiences. For instance, students applied a first order model to a capacitor lab in Week 4 of the semester and used second order system modelling in their sophomore dynamics course, but cited the "jump" into system modeling in the start to the Controls Module in Week 10.

The authors observed the students who did make these connections, or those that had further previous experience such as projects or internships that required that knowledge, were much more successful in the course.

Spring 2020
In the second iteration of the course, the authors chose to focus on: (1) How to incorporate opportunities for students to create more connections with previous course content? (2) How to leverage peer knowledge as a method to support student learning? (3) How to encourage completion of labture activities?

To address the first goal, the authors made strategic adjustments in an effort to improve engagement with lectures and increase the visibility of connections to previous courses and content. The did this through:

- Reading quizzes- online reading quizzes allowing multiple submission attempts (with the goal of 100% scores) were introduced. Quiz questions were carefully created with learning outcomes in mind and explanations added to incorrect answer selections, giving students immediate feedback.
- Topic scaffolding- To support development of student autonomy scaffolding was added to early labtures, providing more step-by-step (lab-like) instructions with a process of slowly removing pieces of the scaffolding as the semester progressed. An example of an exemplar topic the authors tracked was the use and application of voltage dividers (Figure 5).
- Labture Documentation-To encourage reinforcement with the theoretical content all labture guides infused specific call backs to lectures, reading and other concept checks. The concept questions are intended to coerce the students to think more critically about what they are doing. An example concept question would be "Explain why (without using math) the equivalent resistance of two resistors in parallel is less than either of the individual resistors."
- Pre-labture work- Strategic pre-labture exercises students complete prior to every class were introduced. These normally consist of a combination of background reading (bulleted above), finding information on a component online, running through sample calculations and practicing a circuit build. These were assessed for completion and could not be submitted late.

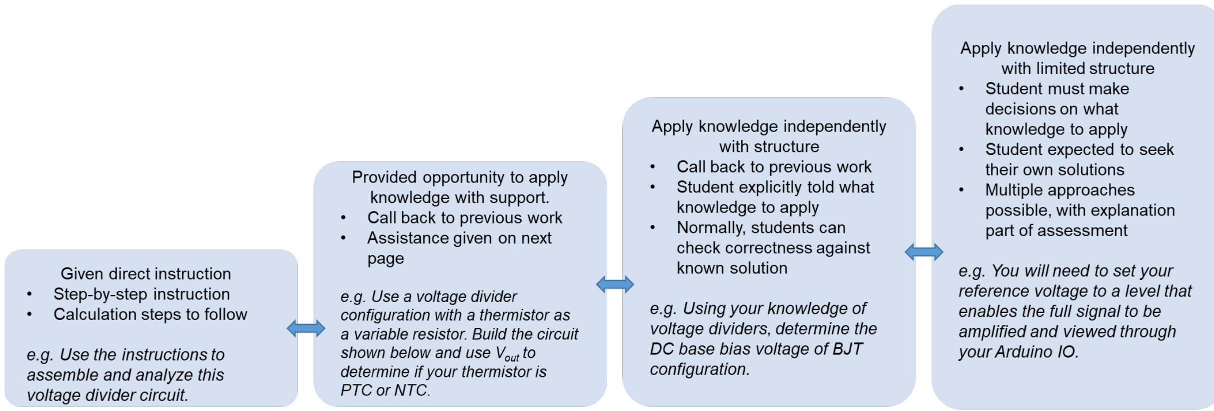

Figure 5: Scaffolding was added to the labture guides to support students with a bit more instruction on earlier labs, explicitly calling out connections to previous content, and then ultimately testing a student's knowledge of previous content through application.

How successful were connections facilitated in course content? Student feedback indicated they found value in the shared theory and practical aspects of the course, as well as the scaffolded approach:

> *"I really appreciated having lab almost every class because it helped me understand the connection between lecture and real-world application."*
>
> *"My partner and I had no idea what to do in the beginning, but we eventually got the hang of it after learning from our mistakes. The labs probably did the most facilitation."*
>
> *"The reading quizzes helped my learning…"*
>
> *"…labs and problem sets help me see the application side of the theory."*
>
> Some students noted it was not until much later that they were able to make the connections.
>
> *"I would suggest making an outline of every module and presenting that before a new one is started. Often I was confused about how things were connected in the module until the very end."*
>
> *"I think it would be helpful to provide summaries at the end of the modules on what was covered and how it plays into the next module."*
>
> *"It was a few weeks after we build the bridge rectifier and did the ECG lab where it really hit me what we were doing in those labs."*

On exams, the authors focused on conceptual explanations in addition to problem solving, such as the examples below. This provided some indication on how well students understood the higher-level concepts in this scaffolded approach. Students achieved 87% and 81% (n=32) respectively on the questions in which these concept checks were included.

Example Exam Question 1: Explain how the order in which the resistor and capacitor in low-pass and high-pass filters create the output intended for each.

Example Exam Question 2: Explain what the purpose of a voltage follower is and how it achieves that purpose.

The second goal, of leveraging more peer learning to supplement learning gains used a number of strategies:

- Group-to-group interactions- Labtures were still completed with partners, however concept questions were designed requiring partners to discuss with other pairs or share data for a more comprehensive dataset.
- Group exams- Students worked in their partner groups for the practical portions of their examinations. Due to the move to remote learning in Spring 2020, the theoretical portion of the exam was converted to a comprehensive take-home exam where groups of four (the table pods) could work together, providing a statement of contribution with their exam.

How well was peer knowledge leveraged as a method to support student learning? This was perhaps the most successful aspect of the course design. When asked, "What helped your learning in this course?" students replied with:

> *"I appreciated the collaborative environment that was fostered throughout the course. I work well when working through problems with others and the lab partner focus helped this."*
>
> *"My partner and I usually tried to work through the problem for a good while before asking though, which often times resulted in us figuring it out which I think was pretty valuable."*
>
> *"I relied on my peers and especially my lab partner to help aide my understanding of the material of the course."*

Attendance in class was over 90% throughout the semester (including the move to remote learning) with students noting, "They don't want to let their partner down" as a motivator to attend class.

To address the third goal of labture completion, each labture was given a set of bulleted deliverables that were due at midnight the following Monday as a low-stakes 10 points each, assignment. These deliverables include key data collection and observations, concept check answers, and some worked out calculations. This allowed students a weekend and a class period to look through each labture guide outside of class, attend office hours, and ask questions in class prior to submission.

Were students encouraged to complete labture activities? Submission (non-zero) rate across the semester of two sections (32 students) was 96.8% with an average grade of 86% (Table 2). When students were asked what *they* did to improve their learning they noted:

"To help my learning I went to every class and stayed up to date with course material. I also spent time outside of class in the lab if something was unclear or wasn't completed."

"Staying after class to finish parts of the lab we needed for the deliverables before the weekend really helped us not fall behind on Monday so we could effectively get the deliverables turned in on time."

It was noted, however, that students felt rushed through the lab and it was observed in class that they would often skip through the theoretical front-matter of the lab, the motivation for the activity, and move right to the methods. This had the unintended consequence of not getting across the point of an activity as is reflected in some of the end of semester course comments. Students also commented on feeling rushed and felt that the lab activities were too long:

"I also liked how there was a daily lab component but when we were on campus it seemed to be rushed and most of the time I didn't understand what I was doing until much much later."

"I could have forced myself to understand material more as we went, instead of cramming at one time. Especially since material builds on each other, its crucial to fully understand as you go."

"I suggest not having labs that take twice the alotted time and making students stay 30 minutes after class after an already lengthy class. This was very frustrating."

Students' overall impression of the course found tremendous value in the mixed content, recognized the utility of lab deliverables and the PSS-style classroom environment:

"Having the professors going around the lab explaining things while we were working on it was the best way to learn in this course, and when I got stuck that was usually how I ended up figuring out the problem."

"The practical labs in this course often befuddled my understanding of the subject matter, so the lecture to open up class really helped. While you guys could have just said "read and come prepared" we went over the key concepts related to lab that helped facilitate personal understanding of the material."

"Having the lab deliverables for only the main parts of the lab and not focusing on the formatting of them really helped my understanding of lab materials. In other courses, too much emphasis is placed on the formatting of the lab reports"

There was still a mixed reaction to the "lab every day" approach, with some students requesting a more traditional approach.

"A little more background and onboarding before the course began - I felt a little blindsided by the content"

"It might be helpful to consider restructuring the class so that labs and lectures are on different days. I thought that lectures were often rushed."

"I suggest having one or two days a week being lecture and the other day being lab. I felt we rushed through lecture a lot and I was left being confused, and then when we would transition into lab, I would be confused in lab because things from lecture were unclear because we rushed."

Of the 32 students surveyed on final course evaluations, 90% or higher felt they had achieved or highly achieved the learning outcomes completed that semester (one was dropped to reduce workload and relaxed emphasis on another, hands-on outcome, when the course moved to remote learning).

Particularly important for this semester, students felt well supported and had a strong sense of community with their peers in this course. Students responded 93% or higher in agreement that the course built community with their peers, was inclusive and supportive to learning, and that the classroom environment was conducive to learning. Of note in the comments:

"Lab time was always incredibly joyful and the attitude in the room was always positive. We were empowered to learn to master the material and class time and office hours were always super inclusive."

"Opportunities were presented for you to learn more about the topic. You gained more knowledge obviously, but you also learned by being in a group or having a partner. Finally figuring out a concept after being confused feels great."

"This was probably my favorite classes this semester even though I know I didn't make my best grade in it."

The final class average was an 87% (B+) with a high of 94% (A) and low of 67% (D+). The assessed work saw a slightly smaller spread compared to the previous semester. The shift to remote learning did affect the overall grading scheme (dropped final practical exam and ECG project was only data analysis and technical run through, no physical build).

*Table 2: Assesment summary of Spring 2020 semester across two sections. *items denote those completed remotely*

Assessment	Average (n=32)	Low	High
Labture Deliverables	85.6%	55.0%	97.0%
Problem Sets	86.5%	59.0%	98.0%
Project 1	87.0%	49.0%	97.0%
Project 2	87.7%	67.5%	100.0%
Project 3*	98.0%	90.0%	100.0%
ECG Project*	83.5%	62.5%	96.3%
Midterm Practical	92.4%	72.0%	90.0%
Midterm Theory	90.5%	54.0%	100.0%
Final Individual*	77.2%	47.5%	98.8%
Final (Group) Take-Home*	86.7%	62.1%	100.0%

The emphasis for the Fall 2020/Spring 2021 academic year was to improve the remote learning aspects of the course. Feedback from Spring 2020 students noted the lack of group engagement, the difficulty in remaining engaged in online lectures, and the isolation felt during difficult topics after the shift to remote learning.

Fall 2020/ Spring 2021

The course was offered in a blended modality in which students could opt to take the course remote or in person, and accommodations would be made for students to quarantine when necessary. The course met synchronously in person with remote students calling in via Zoom. All students went remote after the Thanksgiving break. Goals for this iteration of the course were to (1) provide hands-on learning in a remote environment, (2) achieve some form of partnered and group learning.

To support goal one, each student was provided a take home kit including the Arduino Uno kit, breadboard, all circuit components, leads, transducers, hook-up wire, wire strippers, hand-held multi-meter, craft supplies among other project materials. The purpose of the kits was to provide means for students to complete the same hands-on aspects of the course in their remote environment that the in person class was completing. Since remote students only had access to a digital oscilloscope and limited function generation with their Arduino, some labture guides were created leveraging TinkerCad and Simulink simulations.

To support goal two, the classroom was reconfigured to support socially distanced lab benches (16-student capacity). Students would still work with a lab partner; however, each student completed the labtures at their bench rather than have one bench shared across two students. If a student were remote, their lab partner would still work with them over Zoom.

Student feedback at the mid-term and end of the Fall 2020 semester noted the fast pace of the course, with similar comments to those of previous semesters. Related to goals 1 and 2, student feedback suggested that they did have opportunities of peer learning. Of the 24 students surveyed, 100% agreed to. "This course has helped me build community with my peers." When asked what supported their learning in the course, students noted:

> *"I also liked all the group projects we did since they were a good way to learn while getting help from my peers."*
>
> *"I think having solid relationships with my peers was very beneficial in this course. There were many times where I was not always 100% on the concepts that we covered in class, so being able to discuss with peers and check my work was super valuable."*
>
> *"Instructors clearly valued students working together and building a community with these values in mind."*

Though overall course evaluations were positive, students did note the transition to remote learning and group work did not translate as well:

> *"I really liked everything we did, I just think the last few weeks have been an unfair amount of work. Especially the final course project really fell on one person to do it."*
>
> *"I think the main problem was a rough transition from in person to online."*

Formative assessment saw an overall higher class average between two sections, with a reduced spread across lowest to highest averages (Table 3). Labture deliverables were completed at a 96.4% rate with 100% submission rate on all other assessments.

*Table 3: Assessment summary of Fall 2020 semester across two sections. *items denote those completed remotely*

Assessment	Average (n=28)	Low	High
Labture Deliverables	92.1%	75.0%	99.4%
Problem Sets	92.8%	81.7%	98.5%
Project 1	93.1%	77.6%	99.6%
Project 2	87.9%	66.0%	96.0%
ECG Project	83.7%	74.0%	96.0%
Final Project*	91.2%	76.7%	95.5%
Midterm Practical	96.0%	80.0%	100.0%
Midterm Theory	90.5%	50.7%	100.0%
Final (Group) Take-Home*	86.8%	70.5%	96.3%

In the Spring 2021 semester the primary goal is to support the fast pace of the course with addition TA support. Undergraduate (UG) TAs have been added to support additional out of class lab time and assistance to complete labture deliverables. Some labtures have been removed from the rotation to allow for more time on others. In addition, the authors are piloting a larger 10-week project with targeted deliverables throughout to determine if this approach helps students with the workload of the course.

Course Observations and Evaluations

Classroom Observation Protocol for Undergraduate STEM (COPUS) observations were completed by a trained member of the Center for the Advancement of Teaching [18]. COPUS uses an online platform known as GORP (Generalized Observation and Reflection Protocol) for real-time data collection [18]. Through GORP, the observer can select codes for observed classroom activity for both the instructor(s) and students. Observations are coded in 2-minute intervals until the class session is over. If the observer makes a mistake, they can note it during the next interval, and adjust the data accordingly by hand, after class. Data is automatically analyzed in GORP and can be exported to excel for further analysis. COPUS observations are limited by the fact that a trained individual must label an in-class interaction/behavior in real-time. Multiple behaviors can occur at the same time and some may be missed. This can create some issues with missed labeling or mislabeling during active learning class activities. Additionally, data are collected in 2-min intervals which can cause some temporal discrepancies in the record.

Observations of student and instructor behaviors were completed on three separate dates, corresponding to a typical class day (2/10/2021), a project working day (10/19/2021), and review session (3/4/2021). From Figure 6 a typical class day saw the instructor presenting 33% and guiding 60% of the time. Students were receiving 36% and working 55% of the time. During the project work day, students worked 62% with 19% of their time spent receiving or talking. During this time, it was noted the instructor spent 76% of the time guiding. The collaborative learning of the course can be demonstrated through observing the student and instructor activities during a typical review session. Students spend 56% of the time talking, while only 41% receiving (coinciding with the instructors 41% presenting). The goal of review session is to have students explain concepts to each other with guidance from the instructor. After a brief overview of topics the review session was facilitated by a student posing a question to the class, followed by each pod discussing and formulating their group response. The groups would then discuss amongst each other with the instructor giving guidance. Importantly, the hands on, collaborative nature of the course can be tracked through these observations.

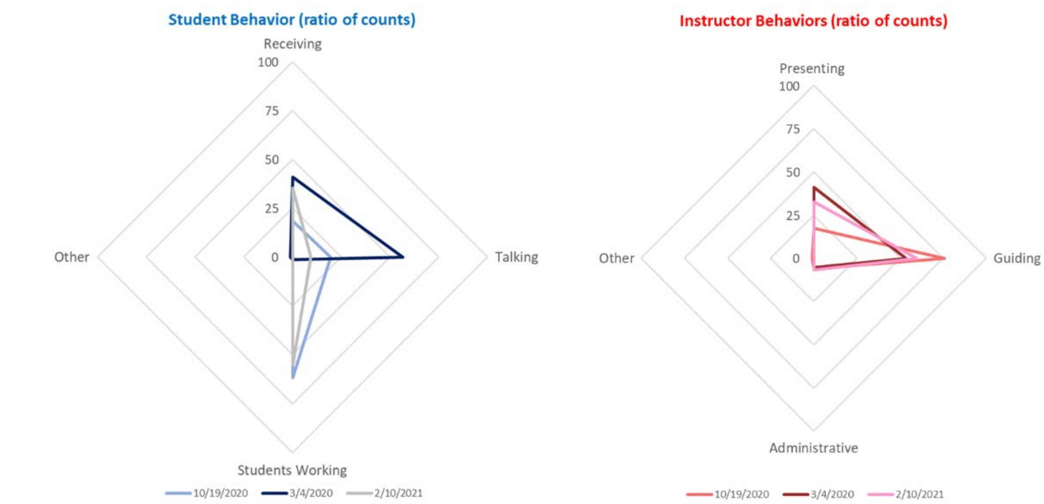

Figure 6: COPUS observations demonstrating the percentage of time during a course period that the instructor and students were engaged in particular behaviors. Course periods reflect typical class lab day (2/10/2021), project work day (10/19/2020) and a review day (3/4/2020). Left: COPUS observations of student behaviors. Right: COPUS observations of instructor behaviors.

In addition to overall behavior, the COPUS evaluations also indicate sub-categories for how class-time is spent by numbers of observations of behavior (Figure 7). On the review day (3/4/2020), confirmation of the whole-class discussion can be observed in the coding of "SANQ"-whole class answering question, "SQ"- asking question and "WC"-whole class discussion in the "Receiving" student category for that date. Similarly, the code "MG"-moving through class, indicates that for about a third of the review session and over half of a typical lab day (2/20/2021) the instructor was in guiding mode, but more specifically, circulating the room.

This categorization can also indicate student activity as a result of instructor activity. For example, while in "Presenting" mode the instructor splits time between lecture (Lec) and Live Writing (LW) while students, on the "Receiving" mode are listening/note taking (L). These plots can be reproduced to show the breakdown of each category across time. Future work in these evaluations will correlate timing of instructor and student behavior to determine if certain instructor behaviors have intended student reactions (i.e. does guiding lead to more questions, student discussion etc).

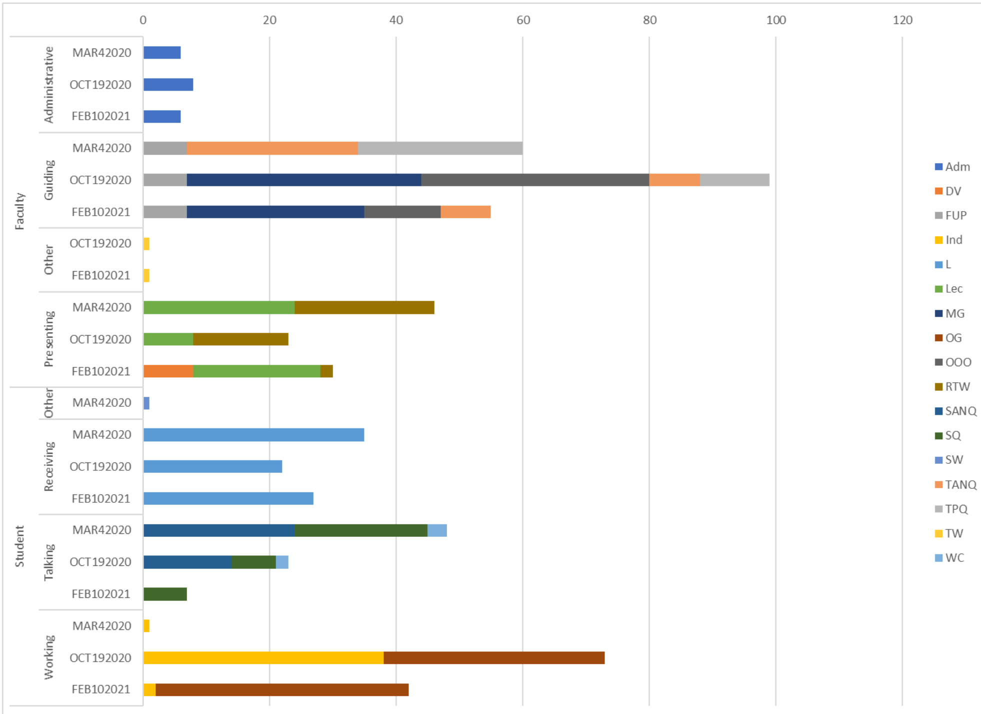

Figure 7: Pivot table produced from COPUS observations across three class days. Codes include: Adm-Administration: DV-Demonstration/Videos; FUP-Follow-Up Questions; Ind-Individual thinking/problem-solving; L-Listening/Taking Notes; Lec-Lecturing; MG-Moving through class; OG-Other group activity; OOO-One-on-One Extended Discussion; RTW-Realtime Writing; SANQ-Answering Question (whole class listening); SQ-Asking a Question; SW-Waiting; TANQ-Answering Question (whole class listening); TPQ-Posing Non-Rhetorical Questions; TW-Waiting (could interact but not); WC-Engaged in Whole Class Discussion

Final course evaluations were administered online for each section of the course during the last week of classes. Across four sections the authors have collected 60 student responses and summarized these in the Tables below. The qualitative portion of the evaluations asked students to reflect on their role, the instructor's role, course artifacts, and classroom environment on their learning. Summaries of these have been given in the Iterative Course Design section of this paper.

Final Course Evaluations Qualitative Data (Course level questions)

1.) What did you do to help your learning in this course?
2.) What could you have done to improve your learning in this course?
3.) What helped your learning in this course?
4.) What suggestions do you have to improve the learning in this course?
5.) Our Department Values are integrity, empowerment, inclusion, growth, compassion and joy. To what extent did this course embody these values? What suggestions for improvement do you have?

Quantitatively, students were asked to rate how highly they achieved the course learning outcomes (Table 4). Most students felt they achieved or highly achieved every learning outcome of the course. Notably, outcome 4 and 5 show substantially lower achievement. These were the course learning outcomes dropped during the Spring 2020 semester, resulting in the cancellation of the final project. Learning outcomes 1 and 7, referencing Arduino and their lab bench saw the highest levels of achievements across the 4 cohorts. This is an expected and promising outcome as these were the learning outcomes addressed every day in the labture mode of learning.

Table 4: Final course evaluation: Course learning outcomes achievement

Q #	Question	% - Not Covered	% - Not Well Achieved	% - Somewhat Achieved	% - Neutral	%- Achieved	% - Highly Achieved	% - Achieved or Highly Achieved
1	Students will be able to apply principles of digital and analog circuits for system analysis and design	0.00	0.00	0.00	8.47	55.93	35.59	91.53
2	Students will understand how and when to apply amplification, filter circuits, and sampling for analog and digital signal processing for a varitey of applications.	0.00	0.00	1.69	10.17	66.10	22.03	88.14
3	Students will understand the principles of instrumentation and develop instrumentation for a variety of systems.	0.00	1.69	1.69	6.78	62.71	27.12	89.83
4	Students will be able to combine signal analysis and instrumentation to create both open and closed loop control systems.	0.00	1.69	3.39	27.12	45.76	22.03	67.80
5	Students will demonstrate an awareness of and appreciation for stakeholder perspecives in engineering design of control systems and instrumentation.	1.69	5.08	11.86	11.86	45.76	23.73	69.49
6	Students will be able to communicate analysis of systems in a varitey of professional contexts.	0.00	1.69	6.78	16.95	44.07	30.51	74.58
7	Students will be able to use electrical test equipment such as power supplies, oscilloscopes, multimeters, and function generators to test, debug and prototype electrical systems.	0.00	0.00	0.00	3.77	32.08	64.15	96.23
8	Students will develop an ability to critically analyze instrumentation and control systems.	0.00	1.92	5.77	7.69	57.69	26.92	84.62

The course evaluation also asked students to respond with levels of agreement to specific course outcomes. Importantly, 96.7% of the students surveyed agreed or strongly agreed that the course was inclusive, supportive, and conducive to learning. Community and Engineering efficacy were also highly regarded in this course. This demonstrates the positive impacts this type of pedagogy has on inclusive practice and student outcomes.

Table 5: Final course evaluation: Course outcomes

Q#	Question	% - Strongly Disagree	% - Disagree	% - Neutral	% - Agree	% - Strongly Agree	% - Agree or Strongly Agree
1	This course has given me a better understanding of engineering and what engineers do.	0.00	0.00	6.67	36.67	56.67	93.33
2	This course has broadened my interests in engineering	0.00	6.67	6.67	41.67	45.00	86.67
3	This course has helped me build community with my engineering peers.	0.00	0.00	5.00	33.33	61.67	95.00
4	This course reflected a positive, inclusive, and supportive classroom culture.	0.00	0.00	3.33	23.33	73.33	96.67
5	The classroom environment was conducive to learning.	0.00	0.00	3.33	26.67	70.00	96.67

Conclusion

From the quantitative and qualitative data collected, the labture approach has been shown to improve student performance outcomes as well as contribute to an inclusive classroom environment. The PSS-style approach to lab activities has also demonstrated an effective means to simultaneously engage students in the practical (hands-on) and conceptual topic of the course.

Though the authors are still navigating the balance between student expectations, appropriate labture workload, and efficient course delivery, the labture model has proved to be an effective approach to integrate and generalize learning across historically distinct courses, engage students throughout long classes, and create an inclusive space for learning. Student autonomy, peer collaboration, and efficacy in course learning outcomes have been demonstrated in summative and formative assessment.

While others reading this paper may not have the capacity to model an entire course from these activities, this approach can be adapted to suit individual projects, lab activities, or PSS sessions. The authors will close this paper with key points in approaching this form of course design:

- Stay student learning centered and not content driven. The authors described their experience with working through the activities in the book, *Building a Pathway for Student Learning.* The posters generated during this process served as a filter for whether or not to implement a certain activity or topic. It also gave a clear path of knowledge dependencies. If a topic or activity did not align with the overall goal(s), it was not covered.
- Ensure the course is well supported with instructors and TAs. Even in the authors' small class sizes of 15-18 students, 2-3 people were required daily to achieve the real-time observations and reactions necessary to maximize the learning gains. Office hours were essential to support students with outside of class work and students with additional learning needs.

- Be transparent with students about the course design. Student feedback in the early iterations of the course pointed out that having a "road map" would help them see the bigger picture of what they are learning. The course design posters and module content are made available to the students. In addition, each lecture has dedicated time to discuss connections with previous content, and where the topics are leading.
- Get regular feedback (and discuss it with the class). In this paper, the authors have shared the methods in which they gather regular feedback. This mode of learning is not familiar to the students, and while some observations can be made in class, student feedback is critical to adjusting to the cohort. Feedback has allowed the authors to correct practices that were felt to be exclusive (for example in one set of feedback it was pointed out an instructor spent more time on one side of the room than the other) and to either negotiate or explain certain practices the students viewed negatively. Importantly it also gave real-time feedback to the instructors on the positive aspects of the course, providing a framework for any future instructor.

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Survey Questions

Module Reflection Survey

Question 1. How well did your team follow through on your original plan of action? What changed and why?

Question 2. For each team member (including yourself) justify the score you assigned. List contributions, comment on effort and attentiveness, or describe anything else you feel helps scoring.

Question 3. Reflect on your role within your group. What were your strengths? What were areas of improvement you feel could have been made as a team member?

Question 4. What recommendations do you have for future teamwork in this course?

Question 5. Reflecting on the character virtues we are focusing on in this course, pick a virtue you think you most exhibited during the Power module of the course (week 1-4) and describe why chose that virtue. Which virtue would you do you think would be important to work on/focus on in this next module?

Start-Stop-Continue Questionnaire

1.) What is working? What should your instructor(s) CONTINUE doing for your learning in this class?
2.) What should your instructor(s) START doing that would help your learning in this class?
3.) What should your instructor(s) STOP doing that is hindering your learning in this class?
4.) Any other comments/suggestions for your instructor(s)?

5.) The Engineering Department Values are integrity, empowerment, inclusion, growth, compassion, and joy. To what extent does this course embody these values? Are there particular values you think this course best embodies? What suggestions for improvement do you have?

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