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Impact of flipped labs and lectures on student outcomes during the pandemic for a lower division Computer Engineering course

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Abstract

We present a study of the flip classroom model at a minority-serving institution, which is one of the largest and most diverse American four-year universities. We motivate the flipping of the lab instructions on the quantitative comparison of the student outcome in Fall 2019 and Spring 2019. This paper presents the setup, the outcomes, and student perception of using flipped instructions for the lab before the pandemic (Fall 2019), during the emergency transition to online instructions (Spring 2020), and after adapting fully online instructions (Fall 2020) for a 200-level engineering class with a typical enrollment of 29-46 students. The success of lab outcomes during Fall 2019 and Spring 2020, coupled with the time management issues reported by students in Spring 2020, motivated us to introduce a flipped approach to lectures as well. To facilitate better time management, we provided weekly announcements, weekly homework problems, and (bi-)weekly lab assignments, utilizing our online learning management system. Students shared that the flipped approach helped them keep up with the topics discussed in class, which we believe is one of the key factors to student success. We present the quantitative comparison of student outcomes (grades) and a summary of student's feedback from Fall 2018 to Fall 2020: before the introduction of flipped labs, during a semester with flipped labs and face-to-face instructions, during a semester with a transition to an alternative mode of instruction with flipped labs, and during a semester with full online teaching with flipped lectures and labs. Our quantitative analysis demonstrated the positive impact of flipped lectures on the outcomes by comparing the data from Fall 2018 to Fall 2020. The surveys reveal the students' sentiments and perceptions of the utilized approach. Additionally, we present "lessons learned" based on the quantitative analyses, students' feedback, and the instructor's observations that could be helpful in a face-to-face environment post-pandemic.

1. Introduction and Motivation

Our institution: California State University Long Beach (CSULB) is one of the nation's largest four-year universities, recognized as Hispanic-Serving Institution, and Asian American, Native American, and Pacific Islander-Serving Institution. CSULB is considered a non-Ph.D. granting, comprehensive university. According to CSULB's Institutional Research (Fall 2019), out of a total of 32,785 undergraduate students, 51.6% belong to NSF-defined UR minority including 59.2% female, 46.9% Hispanic, 4.5% African American, <1% Native American, with additional Pacific Islanders and Filipinos 7%. Eighty-four percent (84%) of the undergraduate population is non-Caucasian, over 55% of students are Pell Grant eligible, and over 50% are first-generation college students.

According to Fall 2020 data, the Department of Computer Engineering and Computer Science (CECS) had a total of 1,526 undergraduate students. The College of Engineering, which hosts the CECS Department, reported 19.9% female, 42,56% Hispanic, 45.18% underrepresented

minorities, and 33.81% first-generation students. We hypothesize that the gender, race, minority status, and first-generation rates at the Department level are similar to those at the College level.

The class: We are presenting the case study of a 200-level engineering class "Computer Logic Design I," with a typical enrollment of 29-46 students. The course covers theoretical and design concepts from digital logic design, during the lectures. Hands-on lab sessions are used to solidify and deepen the understanding of the lecture topics. Lab sessions are also used for learning a hardware description language and tool skills to implement the designs developed during the lectures. Before the pandemic, starting in Fall 2018, we utilized an online zyBooks, customized for this class, and employed active learning strategies. We implemented workshop-style sessions during the lectures where the students were given problems, which they would first solve individually or in groups, and afterward, we collaboratively solved on the whiteboard. This approach helped us pinpoint the most common mistakes and find any issues with understanding the topic, thereby improving the depth of students' knowledge.

The challenge: Although in many aspects the students in Fall'19 appreciated the novel approach to teaching, both end of the term evaluations and the student learning outcomes, especially for lab assignments, showed that many students have been struggling. The course has a steep learning curve, for lectures (theory, design), and labs (hardware description language and tool skills). The concepts build on top of each other, and the class is fast-paced: lack of mastery of the concepts within the first 6 weeks (out of 15 weeks total) usually leads to poor overall performance. The effect has been more visible for the performance on lab assignments.

To remedy the above issues, we restructured the way we introduce the lab assignments during the following semester (Spring 2019). We used the formal presentation method to introduce the concepts and each new lab assignment. We also presented strategies for approaching the lab assignment and writing the report. Unfortunately, this approach does not scale well with the increasing class size. Hence, we wanted to find a strategy for student success that scales well with the growing number of students, without compromising on instruction and that helps free up the lab time that may be used to provide one-on-one time with students.

1.1 Discovery of the Issues in Fall '18 and Spring '19

The motivation for using the flipped class delivery method for the lab instructions is based on the observation of student performance and outcomes in Fall 2018 and Spring 2019. We analyzed the lab assignment submission rate and earned lab grades. Figure 1 shows the percentage of the students who submitted each of the lab assignments, for one section of the lectures and one section of the labs, with the same instructor. There was a total of 6 lab assignments during Fall 2018 (F'18) and Spring 2019 (SP'19). Starting Fall 2019 (F'19), we introduced additional lab assignments. In Table 1, we are providing the mapping of the labs used in F'18 and S'19, to the new labs used in F'19, Spring 2020 (S'20), and Fall 2020 (F'20) for consistency. The lab assignments are mapped based on the complexity of implemented designs, language constructs used, and level of tool skills needed. We will continue to use the names for new labs (1 - 8).

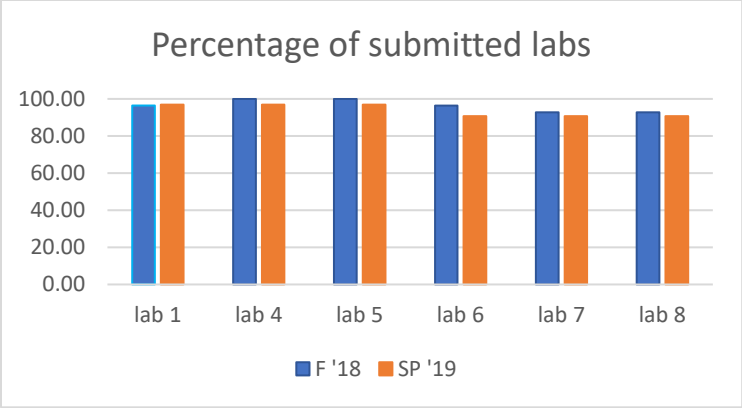

Figure 1. Percentage of the students who submitted each lab assignment

Table 1. Lab assignment mapping between "old" and "new" labs

Semester	**Lab assignments**							
F'18, S'19	old lab 1			old lab 2	old lab 3	old lab 4	old lab 5	old lab 6
F'19, S'20, F'20	lab 1	lab 2	lab 3	lab 4	lab 5	lab 6	lab 7	lab 8

As per Figure 1, more students submitted all the assignments in Fall '18 than in Spring '19, except for Lab 1. The number of submissions was consistently above 90%.

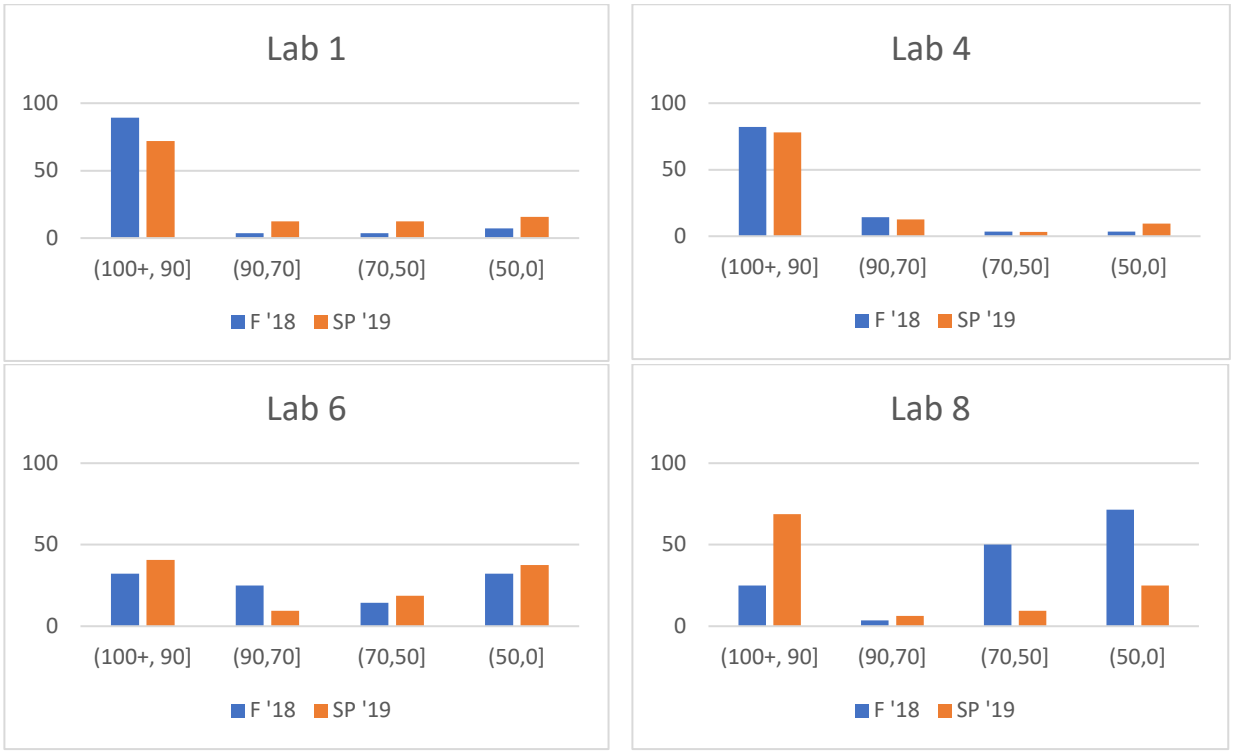

Figure 2. Distribution of student grades that fall into given ranges for F'18 and S'19

Beyond looking at the submission rates, we also wanted to measure overall student performance on the lab assignments, and specifically on the lab assignments towards the end of the semester.

Therefore, we decided to observe the grade distribution for the first, last, and two pivotal lab assignments in between lab 1, lab 4, lab 6, and lab 8. Figure 2 shows the percentage of students who earned grades that fall into the following bins: (100+ including extra credit, 90] for *grade g* ≥ 90, (90,70] for $90\% > g \geq 70\%$, (70, 50] for $70\% > g \geq 50\%$, and (50,0] for $50\% > g$.

Figure 2. shows that the vast majority of the students scored full credit on lab 1 and lab 4. 89% and 72% of the students had the highest score on lab 1, and 82% and 78% for lab 4, were in the highest bin for F'18 and S '19, respectively. However, only 30 and 40% had the highest scores, and 32% and 37% had the lowest score for lab 6. For lab 8, the number of students with the highest score is even lower in F'18 (25%). For lab 8 in S'19, there is some improvement in the students' grades compared to lab 6 in the same semester (almost 69% with the highest scores). We can conclude that a) the students found lab 6 challenging, because it requires mastery of the knowledge from all previous labs, indicating that more support is needed for early lab assignments; b) about 29% of the students were able to "recover" in lab 8, due to improved teaching methods in Spring 2018.

The improvement in performance on lab assignments in S'19, compared to F'18, was due to improvement in teaching methods and to increased time dedicated to one-on-one work. However, further improvements were needed to provide better support for learning design methods, and language and tools skills. To help the students overcome the challenges observed in lab 6, we implemented a more gradual learning experience, by introducing two more lab assignments: lab 2, and lab 3. We hypothesized that the flipped class approach would scale well with the growing number of students, provide comprehensive instructions that the students can refer to at any time, and enable the instructor to dedicate more one-on-one time with students, all of which is critical for their success.

2. Introduction of Flipped Class Method for Lab Instructions

A major overhaul of the labs consisted of 4 components: 1) improvement and a full restructuring of the class' page within the learning management system (LMS) to facilitate the flipped instruction model; 2) upgrade to new hardware (HW) Nexis A7 FPGA[1] kits and Xilinx's software (SW) Vivado[2]; 3) addition of 2 new and fundamental update of the existing lab assignments; 4) creation of the (new, original) supporting materials to facilitate 2) and 3) in the flipped environment.

The LMS adopted by our university is BeachBoard, a customized version of Brightspace by Desire2Learn[3]. Within this environment, we created a course web page that consists of one module for each class topic. Each module identifies the Module Learning Outcomes, resources in the zyBooks, handouts for the topic, and homework assignment problems. It also hosts a submodule for all the corresponding lab assignments. The first module contains instructions, in the flipped form, that support the setup of the new hardware and software. Each lab assignment was designed to support a concept learned in a class (theory and modeling), a subset of language constructs and tool skills. The lab assignments were created to gradually introduce all three concepts and build on top of each other. For each assignment, we prepared a set of video lectures

and corresponding handouts that the students need to cover prior to the lab session. To ensure that the materials are covered before working on the lab assignment, we implemented *"conditional release"*: the file with the assignment is revealed to the student upon seeing the designated content.

We first taught "Computer Logic Design I" with a flipped model of instructions for labs in Fall 2019. The student feedback was uniformly positive as per class evaluation. For each consecutive semester, we introduce improvements identified by the student feedback and instructor's observations from the prior semester. There was no major update of the materials before the emergency transition to Alternative Mode of Instruction (AMI) due to the COVID-19 pandemic. When we transitioned to AMI, we started performing in-class overviews of each lab assignment, with pointers on how to approach implementation, debugging, and testing and uploaded the recording of all instructions to the LMS. Communication in an online environment took longer, and the overview was designed to prevent issues and jumpstart the implementation. We will present a quantitative comparison of student performance in labs in the following four instructional scenarios: (1) without flipped laps, in Fall 2018 and Spring 2019, (2) with flipped labs, in Fall 2019, before the pandemic, (3) during the emergency transition to AMI, in Spring 2020, and (4) in "steady-state" AMI, in Fall 2020. We will follow up with a summary of student feedback from Spring and Fall 2020.

2.1 Quantitative comparison of student performance in labs

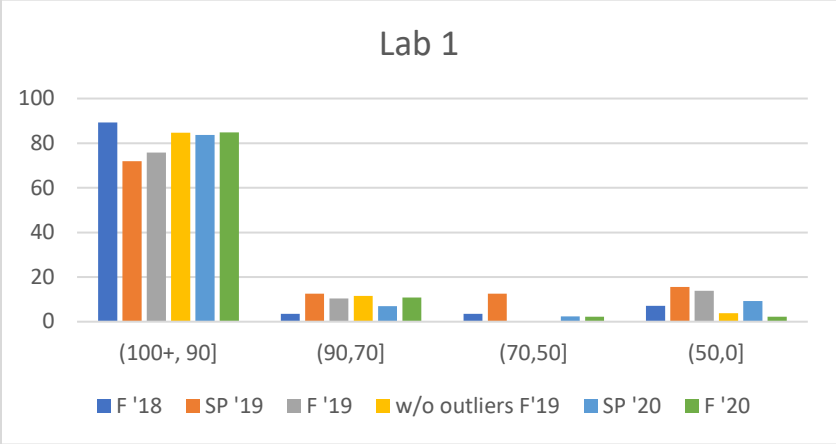

Figure 3. Distribution of student grades for F'18, S'19, F'19, S'20, F'20 for lab 1

Figures 3 – 6 show the percentage of students who earned the grade that falls into the four bins, defined previously in Figure 2, for lab 1, lab 4, lab 6, and lab 8. We will compare the data for Fall 2018, Spring 2019, Fall 2019, Spring 2020, and Fall 2020. In Fall 2019, out of a total of 29 students, two (2) did not submit any lab assignments, and one (1) student submitted only one out of eight (8) lab assignments. We present 2 data points for Fall 2019: "F'19" and "w/o outliers F'19", where "w/o outliers F'19" excludes the three students who did not participate. We believe that presenting both data points shows a fair comparison of the effectiveness of the flipped

approach for the students who were active in the lab sessions. The three students who were inactive in the lab also did not participate in the other assessments. The lab grading was done by the same grader, except for Fall ‘20, but the same rubric has been used. We acknowledge that Fall ’20 grades may have slight variability in grading.

Figure 2 shows that the vast majority of the students successfully performed lab 1: over 80% scored in the highest bin. The exception is S’19, with only 71.88% in the highest and 15.63% in the lowest-scoring bin. After introducing flipped labs (F’19), the student performance is consistent: “w/o outliers F’19”, S’19, and F’20 show around 84% of students in the highest-scoring bin. Additionally, there were also more students in the (90,70] bin and fewer students in the (50,0] bin.

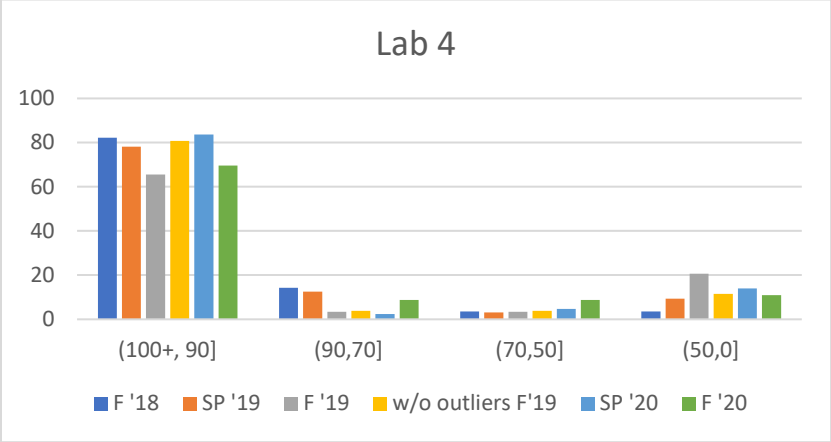

Figure 4. Distribution of student grades that fall into given ranges for F’18, S’19, F’19, S’20, F’20 for lab 4

Figure 4 shows that the trend for lab 4 is similar to the trend for lab 1. However, F’20 has a slightly lower percentage of students who earned the grade in the highest bin, but slightly more students whose grade is in (90,70] and (70,50]. It stands out that during the transition to AMI (S’20), more students were in the (100+, 90] bin and more students were in the (50,0] bin, compared to two other semesters with flipped labs (F’19 and F’20). We believe that the difference is due to the emergency transition. We already started working on lab 4 at the moment when the university stopped face-to-face instructions and paused the instructions for 10 days to allow the faculty to prepare for AMI. We hypothesize that some students might have utilized those extra 10 days to work on lab 4, and some students became disconnected, and the disturbance negatively affected their performance.

Figure 5. shows that significantly more students’ grades were in the (100+, 90] bin, and significantly fewer students’ grades were in the (50,0] bin, for lab 6. *We strongly believe that due to well-prepared supporting materials for all labs, the students were able to successfully finish lab assignment 6 during S’20.* We believe that the *true strength of flipped lab instruction* is shown in the example of the performance for lab 6 during AMI. The lab 6 assignment is the last

one that deals with combinational logic; therefore, it is *likely that lab 6 grade is an indicator of the cumulative effect of learning up till lab 6*.

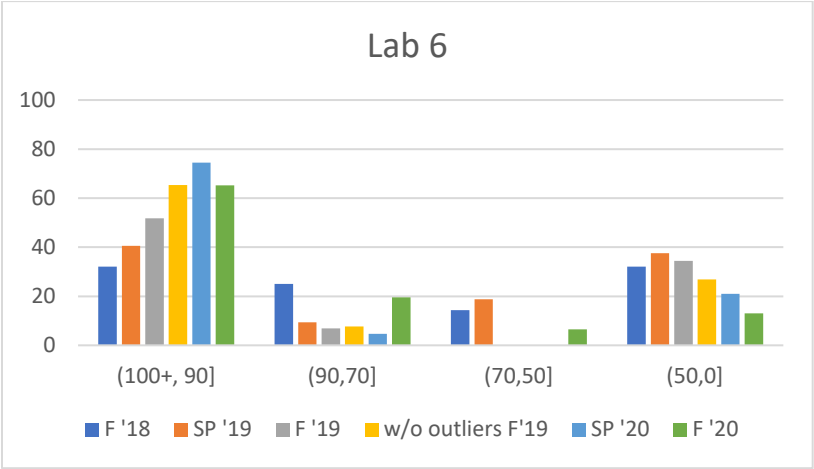

Figure 5. Distribution of student grades that fall into given ranges for F'18, S'19, F'19, S'20, F'20 for lab 6

Figure 6 shows the same trend for lab 8 as for lab 6. During S'19, without flipped lab instructions, the performance on lab 8 is similar to the performance during all semesters with flipped lab instructions. We believe that the success in S'19 is due to the extra effort put in by the instructor to work one-on-one with the students. Such time commitment is very hard to sustain with the increasing number of students in the class. However, the *use of the flipped lab instructions yields the same, if not better, outcomes during the emergency transition to and "steady-state" AMI*.

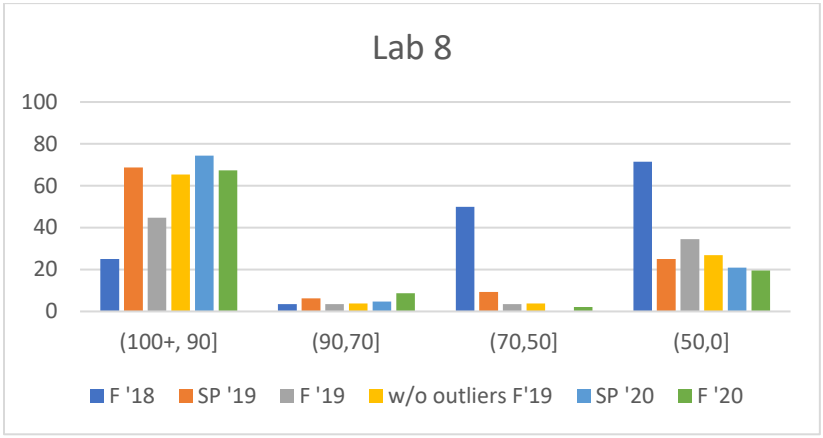

Figure 6. Distribution of student grades for F'18, S'19, F'19, S'20, F'20 for lab 8

2.2 Spring 2020 and Fall 2020: Student Feedback

Feedback for Spring 2020: During the first week of (emergency) AMI, in March 2020, we ran an anonymous survey about the experience during the transition. We asked two open-ended

questions, aggregate results to which are provided in Table 2. Out of 44 students, 15 responded to the survey, making the response rate 34.09%.

Table 2. Cumulative student responses at the beginning of AMI in Spring 2020

Q1 / %	Are there any circumstances that are preventing you from dedicating time or focusing on coursework? Please let me know what they are here (this survey is anonymous) or if comfortable, email me.
40.00	Nothing preventing me
13.33	Lack of self-discipline or rhythm/regularity
13.33	Lack of focus / difficult to work from home
13.33	Lack of communication with others
6.67	Labs are harder online / Hard to install Windows and switch to that OS
6.67	Health issues
Q2 / %	Please provide your feedback about online learning so far. Please be concrete and list the issues (if any) and propose new ideas.
46.67	The system is already good, OneNote for in-class teaching
20.00	It is hard to learn to work with FPGA without in-person help from the instructor and peers
13.33	It is helpful that we have recordings provided
13.33	WiFi/audio issues either on students or instructor's side
6.67	Would like more examples
6.67	Would like to spend more time working on the current lab (vs. on demos)
6.67	Lack of class interaction

The survey indicates that the biggest obstacle was that *the labs are harder in online-only mode* 26.67% (6,67% from Q1, and 20% from Q2). It was particularly hard for the students who used Mac with iOS that does not support the required tools. The setup is difficult and error-prone, even with detailed instructions. Students also report a *lack of self-discipline, focus, and communication with others* (each with 13.33%).

46.67% of the students found the *current setup to be good*, and 13.33% reported that *providing the class/lab recordings were helpful*, where 6.67% would have liked *more examples*, would have wanted *more time for troubleshooting* of the current lab (vs taking in-class demos), and found that *"lack of classroom interaction" as an issue*, each.

Unfortunately, there was no follow-up survey at the end of the S'20, but in the informal setting, the students shared their comments, shown below.
Helpful: the instructor being prepared for abrupt going online; the materials provided; information in our LMS helped with learning and time management; active learning in the class setting; and ability to ask questions.
Obstacles: abruptness of transition, lack of in-person instructions, lack of sleep; tech set up was too hard; and some instructions for labs are insufficient or confusing.
Needs improvement: students need to be more interactive; group assignments/labs.

Overall, the feedback for S'20 was positive. The existing practices that students found to be beneficial are: "*the LMS set up together with the materials (including the materials for flipped lab instructions) and information"* and *"posting of the recordings of the live sessions".* In Fall 2020, we addressed the identified issues *by providing additional materials and help for lab setup*, *devising the strategies for encouraging in-class participation (breakout rooms), and for social interaction (asynchronous discussion forums).*

Feedback for Fall 2020: We ran a survey at the end of Fall 2020, and here we present only lab-related questions and feedback. 11 out of 46 students responded, with a response rate of 24.44%. Note that the students were able to select more than one of the options for each question. *The majority of the students (63.34%) found that videos and pdf materials helped them prepare for lab assignments and that they liked that there were NO quizzes before lab assignments.* An equal number of the students (36.36 %) *found either videos or pdf materials helpful*. Some of the students (18.18%) saw *a value in quizzes that would accompany labs in the future*.

The majority of the students (72.73 %) *agreed that the lab assignments helped them learn the concepts covered in class*. The students expressed contradictory views on *how the labs were synchronized* with the class materials, with almost equal numbers having a positive and negative opinion on the issue. This points that the start and the due date for some of the lab assignments might need adjustment. 18.18% did not find the lab assignments helpful, and a smaller, but the equal number of the students (9.09%) were in favor and opposed to having more lab assignments.

Table 3. Student feedback for lab-related questions (end of Fall 2020.)

Q3) Please select all that applies, regarding your experience regarding materials for lab assignments in the course	
Videos and pdf materials helped me prepare for lab assignments	63.64 %
I am happy there were NO quizzes that accompany the video and pdf materials for lab assignments	63.64 %
Videos materials helped me prepare for lab assignments	36.36 %
Pdf materials helped me prepare for lab assignments	36.36 %
I wish there were quizzes that accompany the video and pdf materials for lab assignments	18.18 %
N/A	0 %
Q4) Please select all that applies, regarding your experience regarding lab assignments	
Lab assignments helped me learn the concepts covered in class	72.73 %
Lab assignments followed were properly synchronized with the classes (they started shortly after we covered the concept in class)	54.55 %
Lab assignments followed were NOT properly synchronized with the classes (they started before or too late after we covered the concept in class)	54.55 %
Lab assignments did NOT help learn the concepts covered in class	18.18 %
I wish there were more lab assignments	9.09 %
I wish there were fewer lab assignments	9.09 %
N/A	0%

Lessons Learned

Quantitative analysis of the flipped lab instructions shows a *positive impact in terms of outcomes: the systematic approach to lab assignments and flipped instructions paid off*. Qualitative analysis shows *that the students felt supported*, especially during the unprecedented disruption due to COVID-19. Therefore, we are currently fine-tuning some of the online materials and methods for synchronous "live" instructions. Anecdotal evidence from Fall 2019 revealed that some of the students did not think of the flipped lab instructions as a form of teaching ("the instructor should be teaching us, not giving us a video"). We proceeded to *educate the students on the research-supported benefits of the flipped instructions* by adding the resources about the benefits to the LMS and talking about them in class. Additionally, some *high-performing students* shared that flipped instructions helped them *perform the lab assignments more efficiently*, i.e., *in a shorter time*. Including the questions about efficiency in future surveys will help understand the impact on the brother class population. We observed that *fewer students were failing the class since introducing the flipped labs* (Table 4)*, and the students who struggled in the class might have not benefited from the flipped approach.*

3. Introduction of the Flipped Class Method for Lectures

To facilitate active learning in a synchronous online environment in Fall 2020 we also implemented lectures in the flipped class model. For each lecture session, we developed and recorded short videos "mini-lectures" in which we present theoretical concepts and short examples, followed by a short quiz. The short quizzes serve as formative assessments that are due before each class. The goal of the quizzes is two-fold: to keep the students current with materials and have the students prepared for active learning during class time. We also provided a worksheet for each session that the student-teams collaboratively solve during the synchronous lectures. We randomly teamed up the students, and we "visited" each breakout room to provide help and troubleshoot the issues. While working with the students, we often discovered concepts that need further clarification, or misconceptions/mistakes. Therefore, we follow up with a discussion of the solutions, issues, and common mistakes, for the entire class. The worksheet solutions are posted after the lecture session. The class recordings are provided in LMS for further review. Both class recordings and "mini-lectures" are available to be viewed and reviewed at the student's convenience. That provides some help to the students with a lack of private/quiet space to work in, and to those who hold jobs. The class LMS was updated after Spring 2020, such that each topic contains a module for each class with the video materials, quizzes, worksheets, solutions, and recording. As the modules have different lengths and complexity, a different number of class sessions is dedicated to each module.

To address time management issues the students reported in Spring 2020, we established a regular rhythm for the course with weekly "news" announcements, a set of mini-lectures and a quiz due before each class, and a weekly homework assignment due at the same day/time. We provided a detailed course schedule to help the students plan ahead of time.

3.1 Impact of the Flipped Class Method for Lectures

To evaluate the impact of the flipped class method for lectures we are going to analyze grades and present the obtained students' feedback. We did not find any correlation between an individual student's quiz participation/grades to their grade on the exam or final grade. We acknowledge that: a) observing only one semester does not show a complete picture of the influence of the flipped lecture on student's outcomes; b) the final grade is a combination of several diverse evaluation methods, including, quiz grade, a lab grade, homework score, and grades from 2 midterms and a cumulative final exam; c) the flipped lab instruction environment also contributes to the overall grade.

GPA and Earned Grades Analysis

Figure 7. shows the class size and corresponding GPA for each of the observed semesters. Please note that in Fall 2020 we introduced the flipped class method for lectures. In Spring 2020, the University allowed, for one semester only, that the students can replace the earned grade with "Credit/No Credit" (C/NC), where C replaced letter grades A, B, and C, and NC replaced letter grades D and F. We hypothesize that having this option encouraged the students to stay enrolled and attempt the final exam, even when the class performance and grades did not indicate a passing grade. In this analysis, we used the *earned grade* instead of the C/NC grade. For example, if a student earned a D, but requested NC, we counted the grade as D.

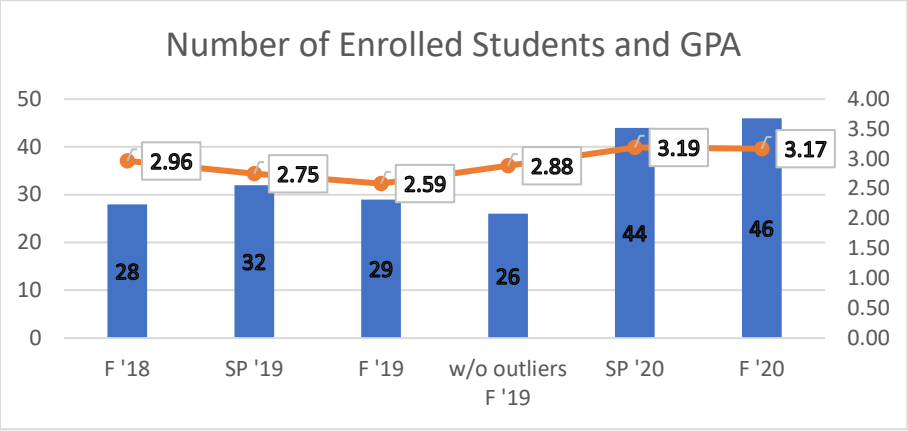

Figure 7. Number of enrolled students and GPA for each semester

Table 4: Pass vs. fail (in %) for all observed semesters

	F'18	S'19	F'19	w/o outliers F'19	S'20	F'20
Pass (A, B, C)	89.29	81.25	82.76	92.31	88.64	91.30
Fail (D, F)	10.71	18.75	17.24	7.69	11.36	8.70

Figure 7. shows that the GPA in Spring and Fall 2020 were almost the same, yet both higher than in the previous semesters, despite the class size in S'20 and F'20 being approximately 1.5X larger compared to prior classes. *The higher GPA even with the larger class size shows that the flipped class method returns sustainable performance with an increase in class size.* Furthermore Table 4. shows the percentage of the students who passed vs. fail the class. The large difference

in the percentages in F'19 and "w/o outliers F'19" is due to having three students who did not submit 7 or 8 labs (out of 8), thus automatically failing the class. *Through the observed semesters, the largest percentage of the students passing the class is for Fall 2020.*

3.2 Student Feedback for Fall 2020

We run a survey at the end of the semester (December 2020) about the learning experience, where 11 out of 46 students responded (response rate 24.44%). The questions about the flipped class and active learning methods applied to lectures are presented below.

From Table 5 we can observe that the *vast majority (81.82%) of the students agree that both mini-lectures and quizzes helped them stay current with the topics, where 45.45% thought that both mini-lectures and quizzes helped them prepare for the problem-solving sessions,* and 18.18% believe that specifically *only mini-lectures* helped them prepare for the problem-solving sessions and stay current with the topics, each.

Table 5. Student feedback about the flipped class materials

Q1) Please select all that applies, regarding your experience regarding mini-lectures and quizzes	
Both mini-lectures and quizzes helped me stay current with the topics	81.82 %
Both mini-lectures and quizzes helped me prepare for the problem-solving sessions	45.45 %
Mini lectures only helped me prepare for the problem-solving sessions	18.18 %
Mini lectures only helped me stay current with the topics	18.18 %
Quizzes only helped me stay current with the topics	9.09 %
N/A	9.09 %
Quizzes only helped me prepare for the problem-solving sessions	0 %

Table 6. Student feedback about active learning

Q2) Please select all that applies, regarding your experience regarding workshop-style lectures	
I liked the option to stay working individually on workshop problems	63.64 %
I liked the option to be in a team, but decide if I would collaborate on a particular problem	54.55 %
I would have preferred to have a team to work on workshop problems during the entire semester (teams would be randomly selected and the same thought)	45.45 %
Having workshop-style lectures helped me gain a better understanding of the problems I was solving	36.36 %
I enjoyed having another student who led the team and shares their knowledge or helps with constructive discussion	36.36 %
I felt uncomfortable asking the students in my group for help	27.27 %
I felt uncomfortable asking the instructor / TA for help (while in a breakout room)	18.18 %
The best workshop-style lectures were the ones where I could collaborate with others	18.18 %
I enjoyed being able to lead the team and share my knowledge or help with constructive discussion	18.18 %
I did not enjoy having another student who leads the team and shares their knowledge or helps with constructive discussion	0 %
N/A	0 %

Table 6. shows that 36.36% of students found *workshop-style lectures* (active learning using Zoom Breakout rooms) *helpful*. The remaining questions have been designed to figure out how

to increase student participation in active learning. As a result, by mid-semester, we had one breakout room for the *students who did not want to collaborate* (as per the survey 63.64% liked to work alone), and several breakout rooms for randomly created teams of up to 5 students (54.55% liked to be teamed up but decide if they want to participate). Also, 27.27% and 18.18% of students felt *uncomfortable asking* for help from peers and the instructor/TA, respectively. 36.36% of the students enjoyed when someone else led the team, but only half of that number enjoyed leading themselves.

As per Table 7. only 27.27% would take a *flipped class in a face-to-face setting*, 18.18% think that they would take a flipped class only for distance learning, and 9.09% thought that flipped is only beneficial in distance learning. Additionally, 18.18% struggled and concluded that it is not beneficial and 9.09% thought that was new, uncomfortable, and not beneficial. Finally, 9.09% struggled but found it beneficial.

Table 7. Student feedback about the flipped class method

Q5) Consider the flipped class method of learning (please select one that is closest to your experience)	
I think it is beneficial and I would like to take flipped classes even with face-to-face synchronous lectures	27.27 %
I think it is beneficial, but I would take flipped classes only with distance synchronous lectures	18.18 %
I struggled with all I needed to work on by myself, and it was NOT beneficial	18.18 %
I think it benefited me because we were synchronous distance learners	9.09 %
This was new and uncomfortable – I needed to learn how to follow such a course, but it did benefit me	9.09 %
This was new and uncomfortable and did NOT benefit me	9.09 %
Based on my final grade, I'll decide if this was worthwhile	9.09 %
I struggled with all I needed to work on by myself, but it was beneficial	0%
I completely disliked and did NOT benefit from the approach	0%
N/A	0%

Table 8. summarizes the answers to open-ended questions about learning circumstances and issues due to the pandemic. The students shared their feelings of *self-isolation*, *being burned out*, *lacking focus and motivation*. Approaching others for social interaction or help was also harder, but some felt that they learned a lot. *Provided materials were good*, could be enriched with *more examples*, but were *convenient* and *facilitated good notetaking*.

Lessons Learned

Having both labs and lectures in *flipped mode* with *active learning* proved to be a *successful teaching* method in terms of *class GPA* and *increased number of students who passed the class*. Having mini-lectures and quizzes was perceived by the students as a *very good method* to *prepare for the active learning sessions* and to *keep up to date with the class topics*. While the videos were *helpful* and allowed for *good notetaking* and *reviews*, not many students think that they would take a flipped class in a face-to-face setting. Some students struggled and doubted the

benefits of the approach, and a few found it beneficial, despite the struggle. Less than a third of the students found it difficult to *ask teammates for help*, and a fifth had issues *asking the instructor*.

Table 8. Summary of answers to open-ended questions about learning circumstances and issues due to pandemic

Q6) List any factors that helped or hindered their learning and share any of the issues that apply only during pandemic / alternative mode of instructions.
Summary of the responses about the class in general (listed in order of appearance): "no external causes hindered learning"; "social isolation causes easier to be burned out, still feels like they learned a lot"; "had lack of motivation and focus"; "had a hard time making social interactions or chat with professor/students"; "shy personality, had issues asking for help, hence breakout room did not work for this person".
Specifically, about the flipped method: "liked, able to play and pose videos, take detailed noted, would take more flipped classes"; "videos and handouts good, more examples"; "appreciate getting the full schedule ahead of time and having the same type of the activities and due dates every week"; "Videos covered more simple examples, ones in class are much harder, frustrated when stuck on a problem, and lost time. Guess that if it face-to-face flipped would be better, now it is overwhelming"

The biggest *obstacle* was the lack of *student participation* in active learning activities in the breakout room that were randomly created every session. We hypothesize that it was hard to work with people who you do not "meet" on regular basis and that towards the end of the semester COVID-fatigue and lack of confidence due to more complex topics may have caused low active participation. We are currently exploring the best way to conduct team sessions in the breakout rooms, such as creating teams upfront and having the teammates create a team contract.

We observed that having a graded quiz with a set due date ensures that the students cover the required materials on time. The vast majority of students completed the quizzes on time (before each class), but only a small number of students would complete the materials required for a lab assignment before its starting date. This resulted in having many students doing the prep work during a lab session itself, instead of obtaining much-needed one-on-one help.

4. Limitations of the Study

We observed the influence of introducing flipped lab instructions within a framework of complete lab overhaul and cannot distinguish the separate impact of flipped lab instructions. We also recognize that due to having a different grader in Fall '20, despite the use of the same rubric, we may need in the future to research how to best normalize the variability in grading. Additionally, we recognize that the survey setup could have been better: we lack surveys for all pre-pandemic semesters, and have only the survey about emergency AMI transition, but not survey about the flipped lab instructions for Spring 2020. Finally, only one semester is not sufficient to fairly evaluate flipped class instructions and we cannot decouple the impact of "flipping" the class and lab instructions. We also acknowledge that it takes time for the student to adapt to a novel teaching method, and for the instructor to explore and improve it.

5. Related Work

Contemporary education has been changing, and many engineering disciplines have embraced flipped classroom method of teaching[4]. Salas-Rueda et al. [5] performed a quantitative analysis of students' perception using machine learning methods for the flipped class with course content similar to ours. The students performed pre-class preparation, in-class activities using design tools, and a lab activity after the class. Students' perception was positive regarding the use of the flipped method and technology. In contrast to our work, the study is based on only one semester. Londgren et al.[6] presented a survey of the use of the flipped class to prepare for teaching clinical skills laboratory. The main benefits reported were positive changes in student behavior, including preparation and better use of time during labs by both the students and instructors. Although they focus on a non-engineering discipline, the classes use a hands-on lab. As such, the studies' conclusions may be pertinent for engineering disciplines with similar lab requirements.

Vielma et al.[7] performed a study of best practices during COVID-19 stay-at-home instructions and found that students' preference is towards a flipped classroom model. Based on the feedback from the students taking lab classes, Lee et al.[8] propose several methods for conducting labs in Fall 2020. One of the proposed options was having a virtual group activity where the students can provide feedback to each other, followed by the instructor's feedback. Our study implements both flipped approach and students working in virtual teams, and we plan to investigate how to incorporate peer feedback in the lab and class based on research by Lee et al.[8] Maarek[9] explores the adaptation of a flipped biomedical engineering course with laboratories to remote learning during the emergency transition. The course and the lab were already flipped before the pandemic and only the content changed. In contrast, we present both a modification of the content and the mode of delivery, during the pandemic.

The method applied by Hussain et al. [10] is the most similar to the one in our paper: for two instances of a class (on face-to-face and another flipped) they observed students' grades, students' reflections using surveys, and instructor, and peer observations. Similar to our conclusion, they observed better students' performance: all students passed and obtained better grades compared to face-to-face instructions. Additionally, Hussain et al. reported that "a flipped classroom model helped high performing students more than lower-performing students." Several prior studies also reported that the flipped approach is beneficial by reflecting on the student engagement[11], motivation, and acceptance by the students[12], but unlike our work, they do not compare flipped approach to face-to-face instructions. Moreover, our work observes the effect on both labs and lectures on several face-to-face semesters, one semester in transition and one in steady-state AMI. Several studies[10, 13, 14] reported initial resistance towards flipped class model amongst the students. However, upon realizing the benefits, more students started liking the pedagogical change[10]. Our study also shows the students having mixed sentiments about the flipped model and its perceived applicability to face-to-face learning.

6. Conclusions

We presented the motivation for use of the flipped lab and lecture instructions, coupled with active learning, followed by the utilized course setup, and applied strategies. We compared the

student outcomes in terms of lab grades for several semesters before, during the emergency transition to AMI, and in the steady-state AMI, showing the positive impact of our approach. The students' perception was overall positive in the beginning. The students fully recognized the amount of support during the emergency transitions was due to the posting of the materials for the flipped lab instruction in advance. The students appreciated the introduction of the flipped lecture instructions and active learning, but sometimes struggled to actively participate or ask for help. The class GPA and the number of students who obtained passing grade show positive trends with both flipped labs and lectures. Over 72% of the surveyed students reported having a positive or neutral opinion of the flipped class, despite the challenging circumstances of the pandemic that have disproportionately hit minority-serving institutions. After seeing the clear benefit of the approach for the students, we believe that the students need to be motivated to take advantage of the flipped mode of instruction. The strategy to allocate credit for class prep activities and enforcement of due dates was largely successful. We believe that the lessons learned with our approach will also apply to the post-pandemic learning environment. We are looking forward to collecting the data from Spring 2021, and beyond, and evaluating the influence of fixed teams for in-class active learning sessions.

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