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Conducting a Blended GD&T Course During the COVID-19 Pandemic: Lessons Learned

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Abstract

The COVID-19 pandemic has created many challenges for lab-based courses. Faculty have been faced with moving all facets of their courses online or with determining ways in which portions of courses could be taught safely in a face-to-face environment. During the Fall 2020 semester, a Geometric Dimensioning & Tolerancing (GD&T) course was offered in a hybrid/blended/flex format within the Department of Technology at Illinois State University. This course was offered in the previous 4 fall semesters in a face-to-face format where students attended 2-hour class sessions twice each week (lecture and labs). Some of the previous lab assignments were set-up to allow students to work together in groups of three or four on a coordinate measurement machine. Adjustments were made during the Fall 2020 semester to minimize the physical distance between individuals in the classroom and laboratory while also giving students the option for accessing the classroom remotely through Zoom and the software remotely through Citrix. Students who felt uncomfortable being around other individuals were given access to the metrology lab outside of normal class hours. This paper will describe the parameters in which faculty at Illinois State University used to make decisions about the mode of instruction in their courses, describe the adjustments that were made to content delivery and lab activities within the GD&T course, discuss changes in how assignments were evaluated, compare student performance on course outcomes with previous semesters, describe student engagement during the semester, and discuss instructional strategies that had positive impacts on student learning.

Introduction

The Department of Technology at Illinois State University, a public R2 research university in the Midwest, began offering a stand-alone course on geometric dimensioning and tolerancing in the fall of 2016. TEC333 has been offered each fall semester since that time. The course provides an overview of basic GD&T terminology, opportunities for students to apply GD&T in a design setting for modestly complex parts, activities where students can apply GD&T within a CAD environment, and laboratories where students inspect parts using calipers and coordinate measuring machines (CMM). All activities in the course are based on the ASME standard for Dimensioning and Tolerancing [1,2]. During "normal semesters" the class meets face-to-face two days per week for approximately two hours each day. Grades are based on labs (30%), weekly quizzes (20%), two tests (30%), and a final exam (20%). Lab activities consist of modeling and drawing assignments using Siemens NX as well as measuring exercises using calipers, a Romer Arm CMM, and a Brown & Sharpe CMM. Weekly online quizzes are used within the learning management system to check students' knowledge of the material. Students are asked to read and complete workbook activities [3] before coming to class, and the instructor then provides short lectures and discussions on the readings and exercises.

In early March of 2020, faculty and administrators across the university worked to move all face-to-face courses to an online-synchronous mode for the remainder of the Spring 2020 semester. The university secured a campus-wide license for Zoom and offered a variety of professional development sessions to help faculty transition their courses to an online environment.

Information technology staff quickly scaled up remote access to all computer laboratories in the Department of Technology.

During the summer of 2020, university administrators, University Facilities personnel, and faculty spent time planning for multiple Fall 2020 semester scenarios because of the COVID-19 pandemic. University Facilities began by evaluating all classrooms and laboratory spaces to determine maximum capacities. They also worked with departments to provide cleaning supplies for offices and classroom spaces.

Mode of Instruction

In June of 2020 the university made the decision to offer as many face-to-face and hybrid classes as possible during the Fall 2020 semester. After University Facilities assessed all classrooms and laboratories on campus to determine maximum room capacities, department administrators then worked with faculty to determine their preferred mode of instruction for the fall semester. Faculty were able to adjust the mode of instruction until the beginning of August.

The initial enrollment for TEC333 was 18 students. One student withdrew from the class in the middle of the semester. University Facilities determined the maximum capacity of the room where this class was scheduled to meet was 12 students. Since the course included precision measurement activities using two coordinate measuring machines, it was determined that some face-to-face interaction was needed to meet the course objectives. The instructor elected to use a hybrid mode of instruction with face-to-face activities for labs and tests, asynchronous online materials for lectures and lab demonstrations, and synchronous online sessions for answering students' questions, test reviews, and for the final exam session. All class activities after the Thanksgiving break, including the final exam, were moved to an online format as directed by university administration.

Sun [4] found that using a hybrid, flipped classroom in a graphical communications course at Embry-Riddle Aeronautical University was effective when used appropriately. Students in the flipped classroom performed better on the final exam than in a previous semester when the course was taught face-to-face. In a study of 175 students in a numerical methods course between 2014-2016 at Alabama A&M University (AAMU), Arizona State University (ASU), and the University of South Florida (USF), researchers found that there was no statistically significant difference between blended instruction and flipped instruction when examining student performance on multiple-choice questions on the final exam. When examining individual institutions, students in the blended classroom at AAMU performed better on the multiple-choice exam items than students in the flipped classroom. In surveys about student perceptions of the classes, students at USF and AAMU preferred the blended classroom environment over the flipped classroom environment. In general, the investigators concluded more research was needed, especially involving non-traditional and under-represented students [5].

Adjustments to TEC333

Content Delivery

As stated earlier, TEC333 is normally scheduled to meet twice each week for approximately two hours each meeting (2 hours lecture and 2 hours lab). After short lectures of the GD&T material, students work on coordinate measuring machine labs or Siemens NX modeling/drawing labs.

The instructor typically moves between the classroom and adjacent metrology lab to answer students' questions. Since University Facilities determined that only 12 students were able to meet in the scheduled classroom at one time, content delivery and lab instructions had to be modified. Weekly lectures and lab demonstrations were recorded in advance. The instructor set-up a YouTube channel to host videos and then linked them through the course learning management system (LMS). Twenty-three content videos and 20 lab related videos were created for the semester. An additional 11 videos were created for weekly overviews, test reviews, and software installation.

Lab Activities

There are two types of lab activities in TEC333. These include measuring activities (e.g., dial/digital calipers and CMMs) and modeling and drawing activities (Siemens NX). LAB 1 typically involves having students measure 10 equivalent parts with dial/digital calipers to generate data for a gage R&R study. That activity was revised so students would not have to pass parts and calipers around the classroom. Instead, students were given data from previous semesters to generate their gage R&R studies. To reduce the number of students who came to campus to work on labs, the instructor divided the class into two groups considering students' preferences. One group of students was scheduled to come to class on Mondays, and the other group was scheduled for Wednesdays.

Another adjustment made for the Fall 2020 semester was to have students complete the CMM labs individually or with a partner instead of with a team of 3 or 4 individuals. Because of this, times had to be scheduled throughout the week for students to complete the labs. The instructor used the Sign-Up function within the LMS to schedule lab times based on student's preferences. Students were also given the option to work on Siemens NX labs from off campus. The software was available to download on their personal computers or to access remotely through Citrix. By taking advantage of these de-densifying methods, the instructor was able to minimize the number of students in the classroom and lab at a single time. During the scheduled class time it was common for only 2-3 students to be in the classroom/lab and 1-3 students to be in the Zoom session.

All 17 students were required to attend class together in person on only 3 days during the semester. On the first day of class a larger classroom with a maximum capacity of 24 was available and scheduled. The instructor covered the typical "first day of class" material and discussed the revised mode of instruction. In addition, students were required to complete the first two tests in person. The instructor utilized two adjacent classrooms for the tests.

Evaluation of Assignments

All assignment evaluation was done electronically. In previous semesters students were required to print out some of the labs and turn them in during class time. For the Fall 2020 semester students were required to upload electronic versions of their assignments to the learning management system (e.g., pdf, Microsoft Word, Microsoft Excel, Siemens NX, Minitab, etc.). The instructor used a Wacom pen and digitizing tablet to mark-up students' files. These marked up files were then returned to the students along with a completed rubric for the assignment through the learning management system. Figure 1 shows examples of marked-up student work.

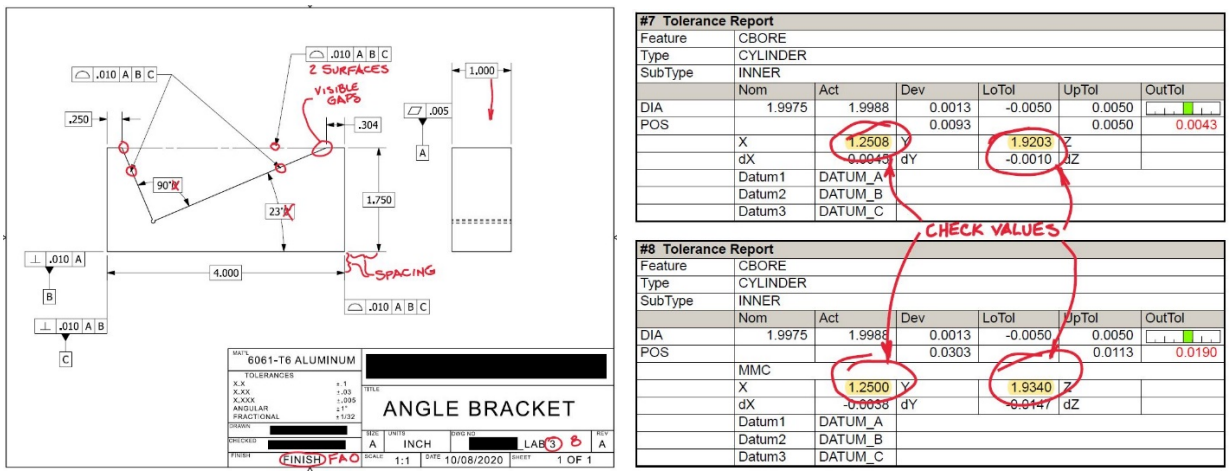

Figure 1. Examples of Digital Feedback.

This electronic process worked well for almost all labs. The exception was a lab which involved designing conceptual functional gages to inspect geometric tolerances on a part. Students were required to make pictorial sketches of the gages and supply all necessary calculations based on the concept of virtual condition. Most students took photos of their sketches and uploaded them to the learning management system. Figure 2 shows a range of quality of the uploads.

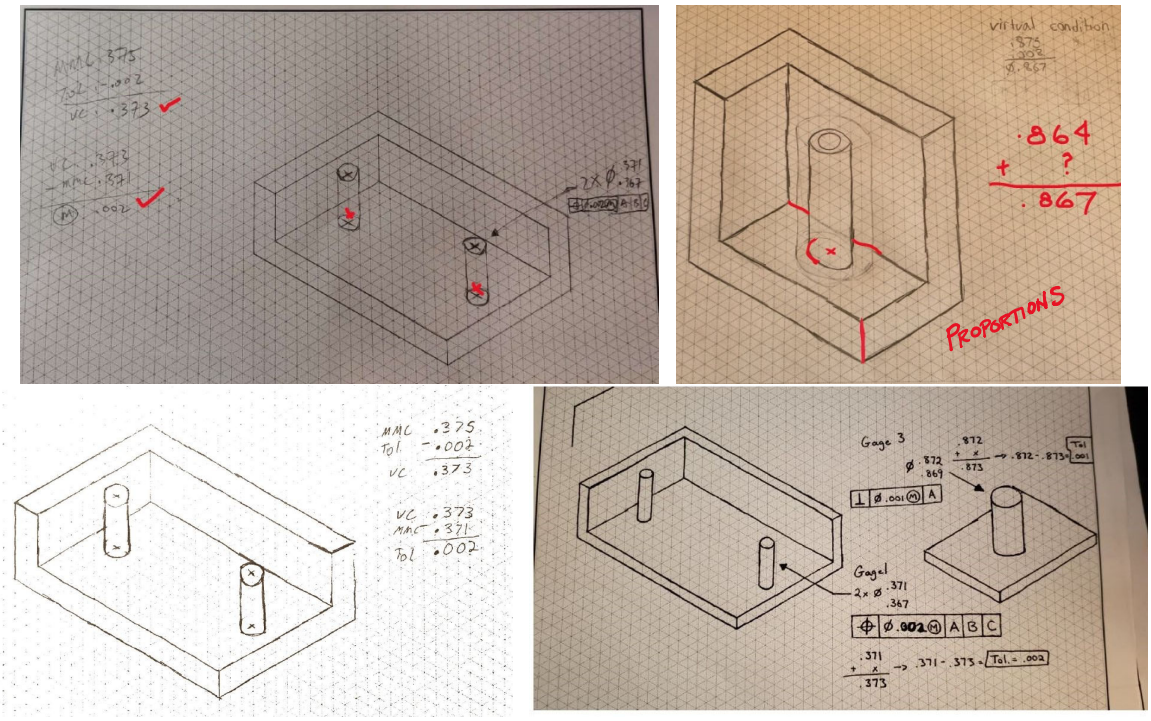

Figure 2. Examples of Virtual Condition Sketches.

Research Questions

Although no formal research study was planned for the fall 2020 semester, there were a few general questions of interest. These included:

1. How engaged were the students with the online, asynchronous materials?
2. What was the relationship between engagement with the online materials and outcomes in the class (e.g., online quizzes, labs, tests, final exam, final grade)?
3. How did the fall 2020 students perform relative to students in previous semesters?

The following section presents data on student engagement and performance. This information will be used to draw conclusions about the general questions of interest.

Student Characteristics and Instructor Positionality

As mentioned earlier, there were 18 students in the course at the beginning of the semester. One student withdrew in the middle of the semester. The mean age of the remaining students was 24 (range of 21-31). All students were Engineering Technology majors in their sophomore (2), junior (6), or senior (9) year. There were 15 males and 2 females in the class. All students completed at least an introductory engineering graphics course and an introductory manufacturing course before the fall 2020 semester. Most students also had completed a second-level constraint-based modeling course and a CNC machining course before the semester.

The instructor had little potential influence/bias on the quantitative data collected. Most of the data displayed in the next section was collected after the completion of the fall 2020 semester. The instructor did take detailed attendance notes during the semester, but this was consistent with previous semesters. Anecdotal observations given in the conclusions must be taken with some level of uncertainty. These observations were based on over 35 years of teaching experience in engineering graphics and 5 semesters of teaching TEC333.

Student Engagement and Performance

Student engagement was assessed using several measures, including attendance in face-to-face and virtual sessions, LMS quizzes completed, and labs completed. The instructor kept a detailed attendance sheet to track face-to-face attendance. Online attendance was tracked by exporting reports from Zoom sessions and LMS interactions. Student performance in the course was assessed on labs (30%), LMS quizzes (20%), tests (30%), and the final exam (20%). Tables and figures in this section examine overall and individual student engagement and performance. Table 1 displays overall student attendance in face-to-face and virtual sessions for each week. Figure 3 shows face-to-face and virtual sessions attended by each student.

Table 1. Student Attendance by Week.

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Attended in person	18	7	14	4	18	7	6	7	17	3	1	1	6	9	0	0
Attended a Virtual Session	5	2	1	1	1	2	2	2	8	1	1	1	0	1	12	17

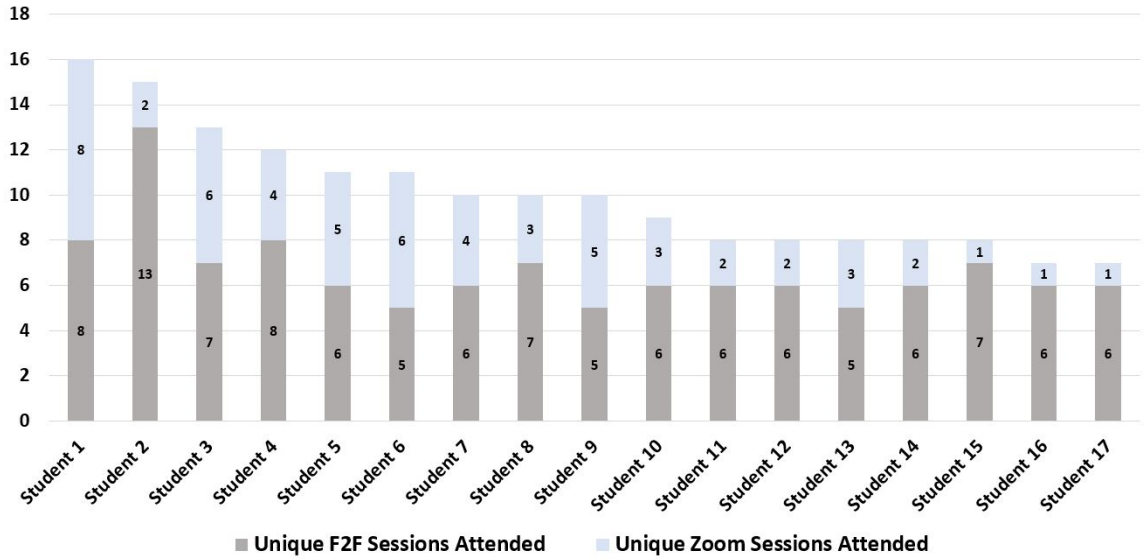

Figure 3. Class Sessions Attended by Each Student.

The data in Table 1 show that face-to-face interactions with students were reduced significantly during the Fall 2020 semester over previous semesters. As stated earlier, all students met together on three days during the semester. These included the first day of class (week 1), test 1 (week 5), and test 2 (week 9). Students completed face-to-face labs using CMMs during weeks 2-4, 6-8, and 12-14. The data in Figure 3 show most students attended 5-8 in-person class sessions. One student consistently attended class every week. There was more variability with virtual sessions.

Table 2 displays the descriptive statistics for hours engaged in class (face-to-face classroom and lab sessions and Zoom sessions), weekly quiz averages, lab averages, test averages, final exam, and final course grade. To examine the relationship between students' final grade in the course and their engagement in class activities, scatterplots were created. Figure 4 displays students' final grades by the total number of in-person and virtual class sessions they attended during the semester. Figure 5 shows students' final grade by the approximate number of hours they were engaged in face-to-face and online class sessions. The types of activities that occurred during the class sessions captured in Figures 4 & 5 included test days, in-person lab activities, and online question/answer and exam review sessions in Zoom.

Table 2. Descriptive Statistics.

Variable	N	Min.	Max.	Mean	Std. Dev.
Hours Engaged in Class	17	9.68	19.82	12.33	3.026
Quiz Average	17	57.00	91.00	77.84	9.107
Lab Average	17	74.00	95.00	85.18	7.056
Test Average	17	60.50	90.50	78.62	8.192
Final Exam	17	38.00	99.00	67.76	15.979
Final Grade	17	64.00	93.00	78.26	7.682

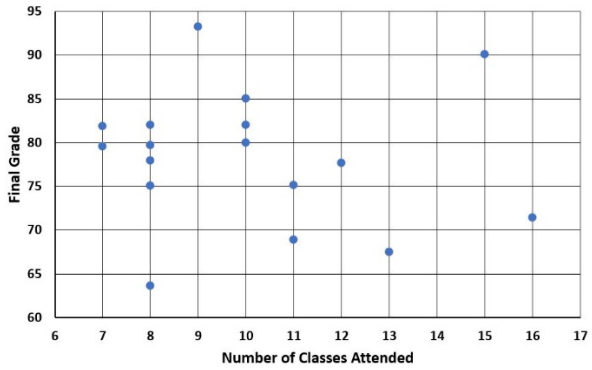

Figure 4. Final Grade by Number of Class Sessions Attended.

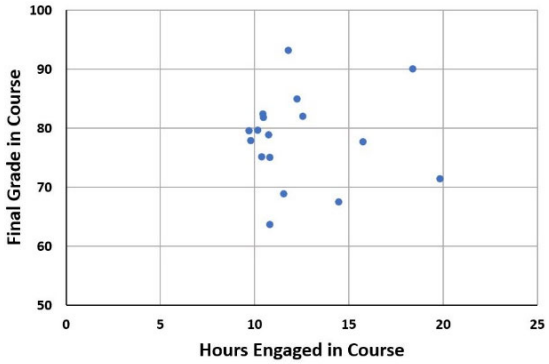

Figure 5. Final Grade by Hours Engaged in F2F & Online Meetings.

The scatterplots in Figures 4 & 5 do not reveal a clear relationship between time spent in class and final grade. The student who participated the most during the semester still earned a low C in the class. The student who earned the highest grade in the class during the semester attended fewer class sessions than many students in the course.

Table 3 shows the number of students who completed the 14 weekly LMS quizzes as well as the average quiz scores. These quizzes were used to assess students' knowledge of the workbook material. Table 4 displays the number of students who completed 13 labs along with the lab averages.

Table 3. Weekly LMS Quizzes Completed.

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Completed Weekly Quiz	17	17	17	16	17	17	17	16	16	15	16	17	15	17
Average Score	91	79	86	77	66	81	91	75	57	81	78	65	44	81

Table 4. Labs Completed.

Lab	1 – Gage R&R	2 – Romer Arm CMM	3 – NX PLATE	4 – Position Verification	5 – NX BRACKET	6 – Brown & Sharpe CMM	7 – Functional Gage	8 – Checking Profile CMM	9 – NX CAM WHEEL	10 – NX SWITCH COVER	11 – NX EOAT PLATE	12 – Measurement Plan	13 – CMM EOAT PLATE
Completed Lab Activity	16	17	17	17	17	17	16	17	17	17	17	17	15
Average Score	77	85	80	83	78	91	74	85	82	81	72	84	71

With a few exceptions, students completed the weekly quizzes and required labs. Some students struggled with the quizzes related to virtual condition (week 5), profile tolerances (week 9), and position tolerancing (week 13). Overall lab performance was satisfactory during the semester.

It was difficult to measure individual student engagement with the asynchronous content in the course. The LMS (Sakai) did not provide reports with time stamped data necessary to track student navigation. Data from YouTube provided overall class engagement with videos. Figure 6 shows the number of times each content video was viewed during the semester, and Figure 7 shows the same for the lab videos. Table 5 displays the devices used to access videos, and Table 6 displays the operating systems used by students.

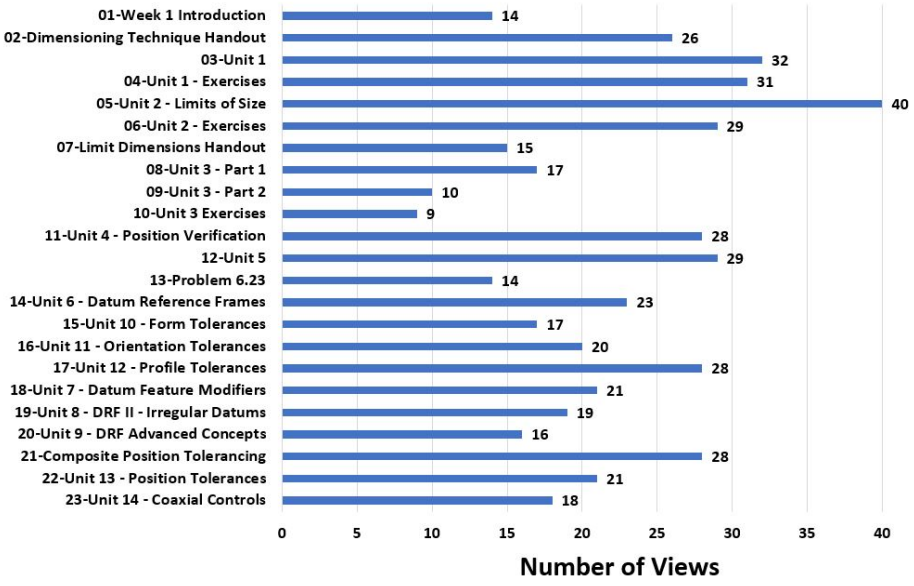

Figure 6. Views of Content Videos.

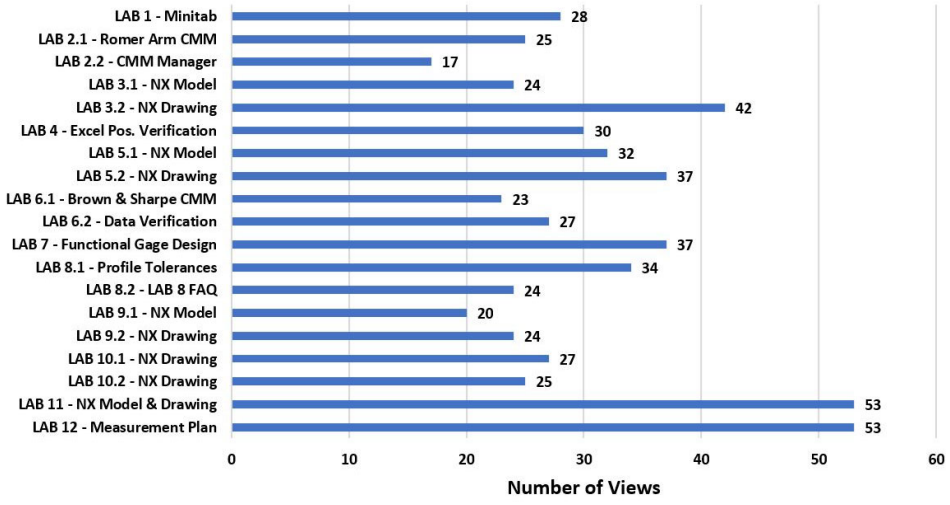

Figure 7. Views of Lab Videos.

Table 5. Device used to Access Videos.

Device	Views		Watch Time (Hours)		Average View Duration
	N	%	Hours	%	
Computer	1,094	92.9%	91.9	90.8%	5:02
Mobile Phone	83	7.1%	9.3	9.2%	6:43
TOTAL	1,177	100.0%	101.2	100.0%	5:11

Table 6. Operating System Used to Watch Videos.

Device	Views		Watch Time (Hours)		Average View Duration
	N	%	Mean	%	
Windows	957	81.3%	75.7	74.8%	4:44
Macintosh	137	11.6%	16.2	16.0%	7:06
iOS	53	4.5%	7.2	7.1%	8:06
Android	30	2.5%	2.1	2.1%	4:17
TOTAL	1,177	100.0%	101.2	100.0%	5:11

Figures 6 & 7 show quite a bit of variability in the number of views of content and lab videos. For example, video 10 covering the exercises in Unit 3 only received 9 views, while the videos for LABs 11 & 12 received 53 views each. Content videos ranged from 4.5 minutes to 22.5 minutes and presented material from the required workbook used in the course. The data from Tables 5 & 6 show that most students viewed videos for just over 5 minutes from a Windows-based desktop or laptop computer. Average viewing times were higher when using a mobile device. Mobile devices tended to be used more often than laptops or desktops when students were completing the CMM labs.

To get a better understanding about student performance in fall of 2020 compared with performance in prior semesters, data was gathered on the variables presented earlier in this paper. Table 7 displays this data from fall 2016 through fall 2020.

Table 7. TEC333 Outcomes by Year.

Variable	Fall 2016	Fall 2017	Fall 2018	Fall 2019	Fall 2020
Students Enrolled	12	19	10	11	17
Quiz Average	85%	87%	92%	92%	78%
Lab Average	92%	88%	88%	89%	85%
Test Average	79%	80%	84%	81%	79%
Final Exam Average	78%	77%	80%	74%	68%
Final Average	84%	83%	86%	84%	78%

The highlighted cells in Table 7 indicate the lowest averages over the last 5 semesters. Except for the fall 2016 test average, students' performance on quizzes, labs, tests, final exam, and final course grade were lower during the fall 2020 semester than in previous semesters.

Student Comments

Eleven of 17 students completed the IDEA course evaluations at the end of the semester [6]. This instrument includes 40 items designed to assess the effectiveness of the course and the instructor. Students' ratings of progress on relative objectives and measure of the quality of the instruction and the course are similar between face-to-face and online courses [7-9]. Table 8 displays the results of 6 items in the instrument that address some of the questions about content difficulty and engagement. Students rated each item on a 5-point scale.

Table 8. Results of the IDEA Evaluations.

Question	Much Less than most	Less than most	About Average	More than most courses	Much more than most courses	N	SD	M
Amount of coursework	0% (0)	0% (0)	100% (11)	0% (0)	0% (0)	11	0	3.00
Difficulty of subject matter	9.09% (1)	0% (0)	27.27% (3)	54.55% (6)	9.09% (1)	11	.99	3.55
Question	**Definitely False**	**More False that True**	**In Between**	**More True than False**	**Definitely True**	**N**	**SD**	**M**
As a rule, I put forth more effort than other students on academic work	0% (0)	18.18% (2)	27.27% (3)	45.45 (5)	9.09% (1)	11	.89	3.45
I really wanted this course regardless of who taught it	0% (0)	0% (0)	54.55% (6)	18.18% (2)	27.27% (3)	11	.86	3.73
When this course began, I believed I could master its content	0% (0)	0% (0)	54.55% (6)	27.27% (3)	18.18% (2)	11	.77	3.64
My background prepared me well for this course's requirements	0% (0)	0% (0)	9.09% (1)	81.82% (9)	9.09% (1)	11	.43	4.00

The data in Table 8 indicate that students felt the amount of work in the course was average, but most students felt the difficulty level was above average. There was a mixture of perceived effort levels in the class. About half the students wanted the course no matter who taught it, and the same number of students thought they could master the material at the beginning of the semester. Almost all students believed their backgrounds prepared them for the course. Only three qualitative comments were provided by the students. These were:

- *The whole course is great.*
- *Not an easy class. The videos helped a lot though.*
- *This course was more difficult than I had imagined, but Professor Branoff was always helpful and provided great feedback on labs and tests. I enjoyed that we were able to still do some labs in person so that we could still get the hands-on experience that we could from the course.*

Instructional Strategies that had Positive Impacts

There were several instructional strategies that were developed prior or during the fall 2020 semester that had positive impacts on student learning. Some of these strategies included weekly online quizzes, content videos, lab videos, and the overall flexible learning environment. The weekly online quizzes have been used since the fall 2016 semester as low stake formative assessments. Previous research has shown that students in an engineering graphics course who engage in weekly online assessments perform better on midterm and final exams [10]. Figure 8 displays a scatterplot of the weekly quiz average by the test average and Figure 9 shows the quiz average by final exam. Spearman's Rho analyses revealed that neither of these relationships were significant (test average by quiz average, $\rho = .333$; final exam by quiz average, $\rho = .170$).

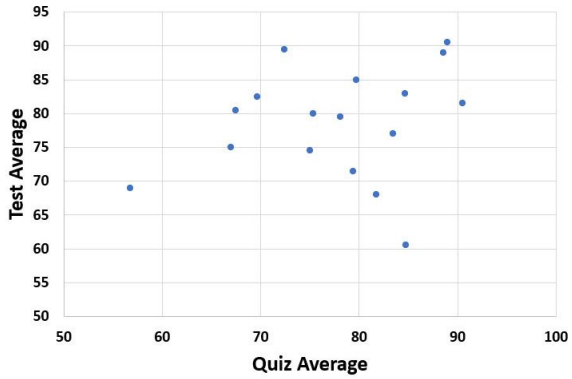

Figure 8. Test Average by Quiz Average.

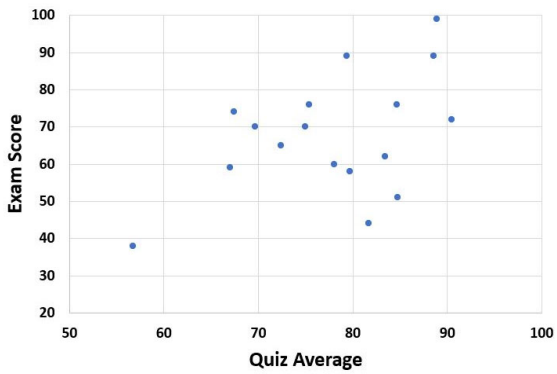

Figure 9. Final Exam by Quiz Average.

The instructional videos seemed to have a positive impact during the semester. Student comments during the semester and on the end-of-course evaluation indicated that they appreciated the depth and frequency of the videos. YouTube analytics data revealed that students were watching many of the videos more than one time and from different types of devices.

Finally, the overall flexibility of the class environment provided students with several options for engaging the content of TEC333. The blended or hybrid nature of the class allowed students to decide how much face-to-face contact they wanted with the instructor and with other students. Since lab computers were available virtually and some software could be downloaded on personal computers, students could complete labs on campus or from home. Face-to-face and online Zoom sessions were held concurrently during the normal class times each week giving students many opportunities to ask questions about labs and course content.

Conclusions

This paper described changes made to TEC333 during the fall 2020 semester and provided data to indicate how students engaged and performed in the course. Many lessons were learned during the semester that were based on data gathered during the semester and/or based on anecdotal evidence. First, students took different approaches to engaging the content. Most students only came to campus when they were required to take a test or required to complete a lab using a CMM, but there was quite a bit of variability in the number of online sessions students attended.

Tracking student attendance in face-to-face and virtual sessions could be done accurately. The missing part of measuring student engagement was measuring how much time students spent working on NX labs and interacting with the content outside of class time or off campus. Some of this was captured in the analytics data of the videos, but video views were not tied to a particular student.

Creating the blended/hybrid environment reduced face-to-face contact compared to previous semesters. There were only three class periods during the semester when all students were in one or two rooms at the same time. It was typical to have only 1-3 students in the classroom or lab at any one time. This was good for preventing the spread of the COVID-19 virus, but it reduced the opportunities for the instructor to interact with students and formatively assess their understanding of the material. Several students, however, commented they were happy to be back in the building using the equipment during the fall 2020 semester.

This environment did force the instructor to find ways for students to complete all the labs individually. This was a positive outcome of the blended environment since it held all students accountable for completing each lab. In previous semesters students could work in groups to complete some of the CMM labs. This created instances where a few students did not experience the full benefits of working with a CMM. Requiring students to complete the CMM labs individually is an instructional strategy that will be retained in future semesters.

Another adjustment that was made for the fall 2020 semester that is planned on being used in future semesters is the electronic evaluation of labs. Using a Wacom tablet to electronically mark up student work was initially awkward and time consuming. By the end of the semester labs were evaluated in comparable times to previous semesters, and there was a significant reduction of paper copies.

There were other conclusions that were based on anecdotal observations. Many students seemed to struggle with time-management during the semester. Students have been used to coming to face-to-face classes, completing labs during class time, and studying and doing homework in the evening, on weekends, or between classes. Since almost all their courses had significant online-asynchronous components, students had more control of how they completed the required activities in each. Some were better at managing their time than others. Some students took jobs during the day that typically would have conflicted with face-to-face classes. Several students decided to live at home (2-3 hours away) instead of near campus, which created interesting dynamics with other family members (e.g., sharing computer resources, finding quite places to study, taking care of children or older adults, etc.). All these things made it more difficult for students to manage their time.

There was an anecdotal observation related to the workbook. Since students were not coming to class every day, it was difficult to verify if they had purchased the required text. In previous semesters the instructor noted that every student had purchased the workbook and brought it to class each day. Content videos during the fall 2020 semester gave overviews of the material in the units, but students had to have the workbook to complete the end-of-unit exercises and weekly online quizzes. The instructor suspects that this had something to do with the lower grades for online quizzes, tests, and the final exam.

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