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Development of an Additive Manufacturing Laboratory Course with the Ability to Accommodate Asynchronous Students

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Abstract: This work-in-progress paper discusses the development of a flexible laboratory course in Additive Manufacturing, and how the course was customized to meet the needs of each student. The faculty members who developed the course identified the need to ensure that every student enrolled in the course has a 3D printer in their possession for the duration of the course to maximize the hands-on applications of the course. Students are given two options for completing the laboratory course depending on their discretionary funds. Option 1 is to purchase a commercially available inexpensive kit, which they build and use for the course and then keep after the completion of the course. Option 2 is to borrow a printer from the department, which they will need to repair or upgrade, use for the duration of the course, and then return to the department at the end of the semester. Any tools or parts are paid for by the department, so students who do not want to invest in a 3D printer can still enroll in the course without any additional out of pocket costs. This decision also allows the students to cater their learning objectives for the course. The students who choose to buy and build their own printers tend to develop a deeper understanding of the parts of the 3D printers while the students who borrow our printers tend to get a broader overview of how the printers work. With the shift to remote instruction during the COVID-19 pandemic, the fact that each student had their own printer allowed for the students to move their printers off campus and complete the required work for the course remotely. The students still gained the hands-on experience that is critical for a laboratory course, even though they were completing the course remotely. This flexibility also ensures that the students who are continuing their coursework via remote instruction can complete the laboratory course requirement for their major without having to attend a laboratory course in person. In the Fall 2020 semester, some students are completing this course in person and some are working remotely and asynchronously. Minimal data was collected at the end of the Spring 2020 semester; but for Fall 2020, the author is collecting data to compare these two groups. The subsequent paper will study if the delivery method has an impact on the students' success and satisfaction in the course. Students' success will be evaluated using the grades on individual assessments and the overall grades in the course, and students' satisfaction will be measured through a survey.

Introduction:

Additive Manufacturing via 3D printing has been a focus of curriculum development for years. Many colleagues within ASEE have published works on the value of incorporating Additive Manufacturing into our coursework [1], [2]. This paper will discuss the development of ME 424 Additive Manufacturing Laboratory. This is a 1-credit laboratory elective that meets the laboratory requirements for the Mechanical Engineering program at Penn State Behrend. This course was developed by the authors of this paper, and this paper will include a review the inspiration for the activities presented in the course, a summary of the major changes made to the course after the first year based on student feedback, and a discussion of how those changes helped the course instructors to transition this course to an online format due to the COVID-19 pandemic. The data presented will compare the performance of students who completed this course remotely in the Fall 2020 semester to the performance of students who completed this course in person. This is a work in progress paper; the course authors will continue to collect data for the duration of flexible learning.

Course History:

The Mechanical Engineering (ME) Department at Penn State Behrend identified the need for an Additive Manufacturing course in 2015. Students in the ME program are required to take a one-credit lab elective as a program requirement, and it was determined the best approach would be to develop a new lab elective in which students will learn a variety of topics about Additive Manufacturing. The course description and objectives were intentionally very open ended to accommodate for the ever-changing technology, and the instructors who teach the course are expected to incorporate the most up-to-date technology into the course. Professor Lani and Professor Johnson (the co-authors of this paper) were chosen as the developers and instructors for this course, given our mutual interest in the subject matter and our prior experience with 3D printing and laboratory instruction.

The first sections of the Additive Manufacturing Lab were offered in the Fall of 2016. The course focused on designing for 3D printing, and the course included 4 multi-week activities. The course met once a week for two hours, which is typical of the other laboratory electives in the ME program.

Activity 1 was focused on learning the basics of 3D printing. The lab periods were spent using CAD to create solid models that incorporate best practices for 3D printing applications, such as designing to avoid supports and tolerancing for 3D printing applications. Students learned how to use Ultimaker Cura [3] as a slicing software. Students learned how to adjust settings in Cura to optimize their prints to avoid supports, to reduce print time, to maximize the quality of their surface finishes, and more. Students exported a .gcode file from Cura and sent this file to either their instructor or to Innovation Commons for printing.

Innovation Commons is “open to all entrepreneurs and innovators throughout Erie County and the surrounding region, including those at the student level, who are seeking a place to organize, collaborate, compose, and construct their ideas.” [4] Students can submit designs to the staff at Innovation Commons for 3D printing, and the staff at Innovation Commons welcomed the students in the Additive Manufacturing course to be present when they printed their designs. The staff would explain the set-up of the machines and demonstrate how to start a print, how to troubleshoot the machines, and how to change filament and answer any questions the students had about the operation of the machines; however, the students did not have hands-on access to the machines.

For Activity 2, students performed a lab where a variety of tensile test samples were 3D printed with varied print parameters, such as print orientation and infill. The students chose the print parameters they wanted to test, and the students assisted in the data collection in the materials testing lab; however, the samples were printed by the course instructors and the staff at Innovation Commons and the tensile testing was performed by the course instructor. This activity was similar to activities presented by ASEE colleagues [5], [6].

Activity 3 was to teach students about 3D scanning and reverse engineering. This activity also has similarities to work presented by ASEE colleagues [7]. Students chose an existing part and observed the process while the course instructor scanned their parts. The scan data was provided to the students who were then challenged to convert this scan data to a solid model and then (if successful), edit the solid model. This activity was designed to fail; the success of this activity was very dependent on what the students chose to try to scan. Transparent surfaces cause gaps in the scan, reflective surfaces skew data, and flat horizontal surfaces are impossible to capture in a scanner that does not have the capabilities to adjust the angle of the laser. Students who capture a good scan struggle to convert their scans to a solid model due to the limitations of existing CAD software and/or the processing speeds and graphics cards in the PCs. Students who can convert their scan data to a CAD model struggle to successfully edit the CAD model. The CAD model is typically unnecessarily complex with many small, faceted surfaces due to the scan process, which makes it difficult or impossible to edit. Grades for this activity are based on students' efforts and a written summary of what they learned in this process rather than whether they were able to obtain and successful scan and CAD model. Students work in groups to develop this summary, so that students who had more success can share their experience with students who had less success, and vice versa.

Activity 4 was a final capstone project, where students designed an assembly, used the proper tolerances, optimized their print in Cura, and then submitted their files to the course instructor or to Innovation Commons for printing. Again, the students did not print their own designs.

The course was run in this format for two semesters. Feedback was gathered from the students via informal surveys and Student Ratings of Teaching Effectiveness (SRTEs). The course was highly anticipated by the ME students. Two sections were offered in both the Fall 2016 and Spring 2017 semesters; and both sections filled quickly with students requesting additional seats in the course. Student feedback was mixed. The students enjoyed the course and learned the topics that were presented to them, but to say that they were disappointed by the lack of hands-on access to the 3D printers would be an understatement. A (paraphrased) quote from one student; "I took a 15-week course on 3D printing without ever touching a 3D printer." (Note: this quote was provided in an instructors SRTEs, which are collected anonymously, so the student cannot be properly cited.) Most of the students expressed similar opinions; that the course content was interesting, but the lack of hands-on access to a 3D printer was frustrating, at the very least, and seemed to be contradictory to the hands-on learning that is expected in a laboratory course.

The partnership with Innovation Commons proved to be a less than ideal solution as well. Innovation Commons was developed to accommodate projects with local industry partners in addition to student prints. Projects with industry partners were given top priority, which meant that sometimes students had to wait weeks to get a part printed, and sometimes it was difficult or impossible for the students to find a time to meet with the staff at Innovation Commons to observe the setup of their designs and ask questions about the machines. The development of this course was planned in conjunction with the staff at Innovation Commons; however, the increased workload on their staff and the increased usage of their machines quicky because burdensome. This format was also incredibly time consuming for the instructors running the course. The instructors found themselves spending many hours in the lab space printing parts, meeting with students to scan parts, troubleshooting and fixing the machines and the prints, in addition to the continuous research required to remain current in this technology. This format was more time consuming for the instructor than any other 1-credit lab course offered in the department.

Development of Current Course Structure:

The course instructors began researching other ideas in the spring and summer of 2017. Initially, we were looking for options to buy multiple 3D printers and build our own 3D printing lab that we can use for this course. There were some major hurdles to this plan. We estimated we would need 10 – 20 printers to accommodate the course, and the upfront costs of purchasing the machines and filament is not trivial. Space was a major concern; at the time we could not identify anywhere on campus to set up a 3D printing lab, and we were researching using space in a neighboring industrial park, which would have been extremely inconvenient for the course instructors and the students. The course instructors would be fully responsible for the maintenance and repair of these printers, which did not bode well for the instructors, given the already heavy workload associated with this course.

As we researched inexpensive options for 3D printers, we quickly discovered the world of RepRap 3D printing [8]. We saw potential: students could purchase an inexpensive DIY kit where they could build their own 3D printer and use it for the course. We envisioned many positive outcomes of this potential course re-design. Students would get to keep their machines after completion of the course and can continue to use their printers for other coursework, including senior design. Students would have the hands-on access to the machines that they desired, including the initial assembly of the machine. Students would gain a deeper understanding of how the machine works, which would be extremely helpful if the students need to troubleshoot the machines later. Students would now set up and troubleshoot their own prints, rather than the course instructors or Innovation Commons staff. The responsibility of the maintenance of the machines would fall solely to the students. The machines would be stored in the student's personal space or an open lab space on campus like the senior design lab, which eliminated the need for a lab space.

We targeted kits that were in the same range as a course textbook ($150 -$250) and could be easily assembled by a beginner. We purchased a variety of kits to benchmark over the summer of 2017, including a Creality Ender 3, a Monoprice Maker Select, and an ANET 8. The instructors built these machines and evaluated them in terms of ease of assembly, reliability, longevity, ease of operation, cost, and safety. At the beginning of the Fall 2017 semester, we allowed the students to choose their own kit. We approved the kits that the student chose before they purchased the printer, and we required them to thoroughly research the kit they were purchasing, especially regarding any safety concerns or any necessary modifications they might need to make to ensure the printer can be operated safely.

For students who were looking for recommendations, we recommend the Creality Ender 3 [9]. The Ender 3 can be purchased on Amazon for around $200. The machine arrives with the base plate and most of the control systems already assembled. The students assemble the machine with the instructions provided, level the bed, and start printing. The machine can be assembled in less than 2 hours (the course instructors completed the assembly in approximately 40 mins). The kit comes with all necessary components and all tools required to assemble the machine. The machine also comes with an SD card with pre-loaded test prints, so once the machine is assembled, the students can print a test print even before they have learned how to use Cura to prepare a solid model for printing. We recommend the Creality Ender 3 due to the safety concerns.

The ANET 8, the Monoprice Maker Select, and many of the other RepRap machines that we considered have a similar flaw; the low quality and inexpensive boards installed in these machines sometimes fail catastrophically due to the power required to heat the nozzle and bed simultaneously. We still allow students to purchase these machines because these machines can be operated safely with the installation of a MOSFET board. A MOSFET board will separate the two heating systems; power required to heat the nozzle is supplied by the main board, but power required to heat the bed is supplied by the MOSFET board. MOSFET boards are readily available and inexpensive (typically < $20). Installation instructions for a MOSFET board on common machines like the ANET 8 and the Monoprice printers are readily available online [10], and the course instructors were able to install MOSFET boards on these machines in about 20 minutes using common tools.

Since we have implemented the new course structure in the fall of 2017, 90% of our students have purchased either the Creality Ender 3 or the Creality CR-10 [9]. The Creality CR-10 is almost identical to the Ender 3 with a larger print volume. The Creality CR-10 is also more expensive (around $500 on Amazon).

Students who do not want to purchase their own 3D printers have the option to borrow a machine that is owned by the ME department. Some students borrow a brand-new machine; they build the machine, use it for the duration of the course, and return it at the end of the semester. Some students borrow a machine that has been assembled and used in a previous semester. These students are required to upgrade the machine they are borrowing to obtain similar hand-on experience that the students who are building the machines get. Students are required to research the machine they have been assigned and submit a summary of the upgrade they recommend. Their summary must include the cost of the upgrade, links for parts and tools that need to be ordered, and the affect this upgrade will have on the printer. The ME department purchases any parts needed for the upgrade and provides any tools necessary. Safety related upgrades must be made first, if necessary. Upgrades that have been competed thus far include replacing the bed, replacing the extruder, replacing the nozzle and heating element assembly (the hot end), replacing the control board, replacing bearings or stepper motors, or adding an automatic bed-leveling system. Some students borrow a machine that needs repair or maintenance; the students are required to complete this repair or maintenance to obtain similar levels hands-on experience as the other students enrolled in the course. The ME department also provides tools and purchases equipment necessary for these machines.

Any students who do not want to store the 3D printers in their homes are offered space on campus to store their machines to use them on campus rather than at home. We found it much easier to place an empty table in a corner of a lab space for students to operate their printers than to find a space for 10 – 20 printers. And since the students are not using these machines during a formal lab period, these machines do not have to be stored in a common room; and as a result, we typically have 3D printers working in a variety of spaces all over campus. Students who are concerned about building their machine on their own or performing their upgrade or repair on their own are given the option to bring their machine to the regularly schedule 2-hour lab period to build/repair/upgrade their machines under the supervision of the course instructor and with the help of other students in the course.

With the implementation of this new structure, the four activities in the course changed significantly. The current course structure includes five lab activities and four learning modules. For clarity, an Activity requires parts to be 3D printed as part of the grade where a learning module is a lecture or discussion during the regularly scheduled lab period where learning is assessed via a quiz at the end of the lab period. Activity 1 became all about choosing the machine they wanted to purchase, repair or upgrade, and then building the machine or performing the upgrade or repair. This is a multi-week activity due to the time required to ship the machine or the parts required for the repair or upgrade.

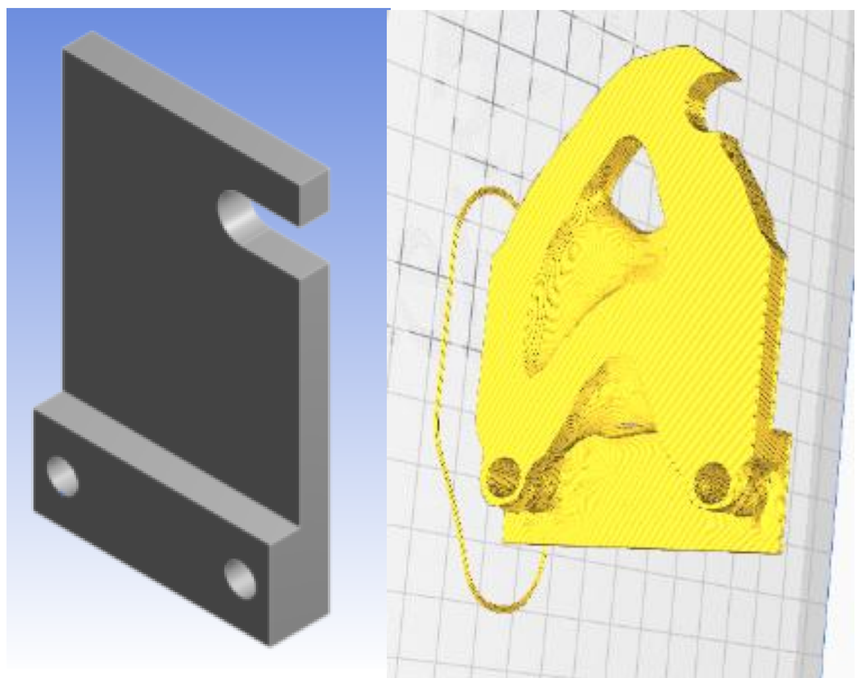

Figure 1: Bracket Before and After Optimization

Activity 2 from the original course content (tensile testing of 3D printed samples) was replaced with an optimization study. The students indicated that the tensile testing lab was interesting and fun, but the course instructors recognize that this data is readily available from similar studies that have been performed using detailed and accurate testing methods and large sample sizes. Course instructors also recognize the growth in the field of coupling 3D printing and optimization. In the new Activity 2, students use ANSYS to perform an optimization study where they remove unnecessary material from a simple bracket based on the stress distribution in the bracket. This activity was inspired by the work of our colleagues presented at the semi-annual ANSYS user group meetings [11]. The resulting optimized geometry is very organic in shape, which is typical in optimization studies, and cannot be produced via traditional manufacturing. However, this organic optimized shape can be produced by 3D printing. The optimization study is completed during a single lab period, and the students print the original bracket geometry and the optimized bracket geometry as part of their grade.

Activity 4 from the original course became Activity 3 for the new course, where the students design and print an assembly. This activity moved earlier in the course structure due to the timing of the new Activity 4: the new Activity 4 requires the students enrolled in the Additive Manufacturing Lab to print parts for the freshman enrolled in EDSGN 100 Introduction to Engineering Design course. In EDSGN 100, teams of freshman design a chassis for a robotic car that follows a line. The freshman teams design the chassis and send their design to the Additive Manufacturing student who has been assigned to their team. Details of this project were presented at last years ASEE conference [12]. The Additive Manufacturing student critiques their design and recommends (or sometimes required) some changes, and then prints the chassis for the EDSGN team. Due to the nature of the project in the EDSGN course, the Additive Manufacturing students are typically working with the freshman between weeks 11 – 13 of the semester, so the design build and print project was moved earlier in the semester. Activity 3 in the original course (3D Scanning and Reverse Engineering) has become Activity 5 in the new course.

For Learning Module 1, the course instructor dedicates a lab period to learning Cura, and the students complete an assessment during the lab period to demonstrate their ability to use the software. For Learning Module 2, the course instructor dedicates a lab period to discussing designing for 3D printing. This discussion includes many of the same learning objectives from Activity 1 in the original course and is delivered as a lecture and discussion during the regular weekly lab period. Students complete an assessment to demonstrate their understanding of these concepts at the end of the lab period. Learning modules 1 and 2 typically occur during weeks 1 and 2 of the lab while students are waiting for their printers or parts to arrive. In learning Module 3, students are assigned a group presentation. Students work in groups of 2 or 3 and research a topic of their choosing of emerging applications in 3D printing. Topics that have been researched in the past include bio 3D printing, composite 3D printing, food 3D printing, 3D printing of concrete for construction applications, and more. Students present these topics during the regular weekly lab period. Learning module 4 focuses on the limitations of 3D printing and includes a lecture and group discussion of things that cannot be accomplished with 3D printing, the cons of 3D printing, and comparisons of 3D printing vs. traditional manufacturing for a variety of applications based on the work presented by Dr. Jaksic in 2015 [13]. This topic is typically coupled with Activity 5 (3D Scanning and Reverse Engineering), because Activity 5 is a clear application of the limitations of 3D printing. Students complete an assessment to demonstrate their understanding of these concepts at the end of the lab period.

Table 1: Summary of Current Course Activities

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Activity 1: Build/Upgrade 3D Printer	■	■	■	■											
Cura Learning Module		■													
Design for 3D Printing Learning Module			■												
Activity 2: Optimization with ANSYS					■	■									
Types of 3D Printing Learning Module					■	■	■	■	■	■	■	■	■		
Activity 3: Design/Build/Print Project						■	■	■	■						
Activity 4: Pandemic Prints										■	■	■	■	■	
Limitations of 3D Printing Learning Module											■				
Activity 5: 3D Scanning and Printing												■	■	■	■

Additional Flexibility Added to Accommodate Remote Learning:

In March of 2020, all our lives changed with the shift to online learning due to the COVID-19 pandemic. Little did the course instructors realize in 2017 when we revised the course that the decision to ensure that each student had their own printer to use for this course would be critical in the spring of 2020. When Penn State announced that we would not be returning to on-campus instruction after spring break in the spring 2020 semester, our students were advised to move their printers home. Students who had been using the ME department's machines this semester were given permission to move these machines home with them with the understanding that they would be returned at the end of the semester, or whenever it was deemed safe for the students to return the machine. At that point, students were working on Activity 3 (the design and print project), and they were able to continue with that project from home. Activity 4 (EDSGN car bodies) was replaced with a pandemic related print. Students were assigned with using their 3D printers to print parts to help during the early stages of the pandemic. Some examples of prints that students chose were headbands for face shields, mask extenders for healthcare workers, bias-tape holders for people who were sewing fabric masks, webcam holders for teachers who were teaching from home, and more. These prints were typically not designed by the students, but the students were given the option to combine activities 3 and 4 and design and print something to aid during the pandemic. Learning modules 3 and 4 were completed via live Zoom sessions, and the quizzes for these learning modules were delivered via Canvas rather than completed on paper. Activity 5 3D Scanning and Printing was cancelled for the Spring 2020 semester.

For the Fall of 2020, faculty was encouraged to offer our courses in a flexible format, if possible. Students were given the option to enroll in a fully online schedule if they did not feel safe returning to campus due to the ongoing pandemic. The ME department was particularly concerned about lab courses. Lab courses are difficult to run well online, and as a result, many of our traditional labs were not offered in an online format. For example, students who wanted to take the thermal fluids lab were required to complete this lab in person, and if a student was choosing a fully remote schedule, they were encouraged to enroll in a different lab or delay their lab course until a future semester where they can safely attend classes in person. The course instructors developed a method of delivering the course in whatever format the students felt most comfortable. Students who chose to return to campus completed the activities and the learning modules during the regularly scheduled lab period. Students who were working from home could purchase their own printer and complete the entire course from their home. The result was that students could still complete a 1 credit lab, which is required for a graduate of the ME program, while maintaining a fully online schedule.

Some minor tweaks were necessary to accommodate the online students. All lectures and discussions completed in class were recorded. Some remote students logged in to Zoom during the lab period and participated in the lecture and discussion, and some students chose to watch the recordings later. All quizzes associated with the learning modules were transitioned into an online format and delivered in Canvas. Activity 1, where the students choose, purchase, and build their 3D printers, was basically unchanged; the only difference was that students who were working online did not have the option to borrow a printer from the ME department due to the logistical and safety concerns associated with distributing the printers. Activity 2, the optimization project, and Activity 3, the design and build project, were unchanged. Activity 4 was semi-permanently changed to pandemic related 3D prints. During flexible instruction, the car project in EDSGN has been scaled back to accommodate EDSGN students working in smaller groups due to social distancing, and as a result, the 3D printing aspect of this project is currently not required. EDSGN students can 3D print parts of their cars for bonus points, but the printing will be done by EDSGN faculty and Innovation Commons.

Activity 5 required the most changes; online students are grouped with in-person students for this activity. The in-person students still scan parts with the course instructors and the staff at Innovation Commons using the scanners available on campus. The online students are required to download a 3D scanning app on their phones and attempt to obtain a scan using one of these apps. A variety of free apps that have been tested by the course instructors are suggested to the students to try, and students can also choose to try a different app. I found the references provided by Mr. Fraley and his peers at Tennessee Technological University and Purdue University a great resource [14]. Students are not expected to purchase an app for this activity and are encouraged to make their best efforts to obtain a 3D scan using a free scanning app.

We have had the best results with photogrammetry, where students take photos of an object from a variety of angles and import those photos into a software program that compiles these photos and generates a 3D shape. Our most successful scans were obtained using Meshroom [15], which is free and open source and can be downloaded to any PC with a Windows operating system. The model that is created typically required significant post-processing to smooth the data, and we’ve had the most success using Autodesk Meshmixer [16] for post processing. Meshmixer is also free and open source. Students can use Meshmixer to clean up the scan data that is exported from Meshroom, smooth out rough surfaces from erratic data, and make their scan geometry more closely represent their actual part. Meshmixer can also be used to make simple model edits, like adding holes or text, but it does not include complex solid modeling capabilities like sweeps and blends or parametric relations. Files from Meshmixer can be exported as an .stl for 3D printing or as a CAD file for further solid modeling work. The grade for this activity includes a required group discussion in a discussion forum in Canvas. In this discussion, each group member shares their experience with whatever scanning methods and post processing methods they used. Students who were unable to obtain a successful scan or solid model share the lessons they have learned about their failure, and students who were successful shared how and why they were able to succeed. All students were encouraged to discuss potential improvements to this process in the future. This includes suggestions for the best types of objects to scan, the best scanner or app (or scanners or apps to avoid in the future), the best software for post processing, and any other tips they should keep in mind if they were to attempt this activity again in the future.

The course instructors also offered flexible due dates for the course to accommodate fluctuating schedules and potentially high workloads due to the pandemic. Activity 1 had a strict due date; students were expected to have their 3D printers purchased, built, repaired, or upgraded within the first 3 weeks of classes. Learning Module 3, the group research presentation, has a strict due date; all students give their presentations either in person or live via Zoom during the same lab period. All other activities and learning modules are simply due by the end of the semester. The course content is delivered during the regularly scheduled lab periods and recorded. Most of the students complete the course in a synchronous manner, completing the Activities and Learning Modules in synch with the timing of the instructor led lab periods, but a few students work completely asynchronously. This flexible hybrid approach was very accommodating for all students, including in-person students who were not able to attend lab in person due to sickness or quarantine.

Summary of Student Performance:

Before delving into the specifics of the data analysis for the Fall 2020 semester, the authors would like to acknowledge that the grades for the course are typically very high, and the grades for the Fall 2020 semester were abnormally high. In general, at least 80% of the students enrolled in the course get A’s in the course. If the students are participating and completing the assignments, they do well in the course. For the Fall 2020 semester, 26 students were enrolled in the course; of those 26 students, one student received a B for their overall course grade, one student received a B+, and one student requested and received a grade deferral (they were unable to complete the course requirements for personal reasons). The remaining 23 grades were A’s (92% of the course enrollment).

The course instructors are hesitant to conclude that the high grades for the fall 2020 semester are due solely to the new flexible course format. Students have indicated that the high grades may also be contributed, at least in part, to boredom. Many activities have been cancelled due to the pandemic, and a few students identified their 3D printers as a welcome new hobby. It is possible that student dedicated more time in the Fall 2020 semester than in previous semesters simply because they had more time to devote to the course due to the restrictions on large gatherings and group activities.

Ten students completed the course fully online (38.5% of the students enrolled in the course). The graph included illustrates the performance of the online students when compared to the in-person students. The deferred grade student has been removed from this data. The difference is not significant enough for the course instructors to clearly conclude which is the more effective method of instruction. Additional data is being collected for the Spring 2021 semester, and these metrics will be evaluated again in the future.

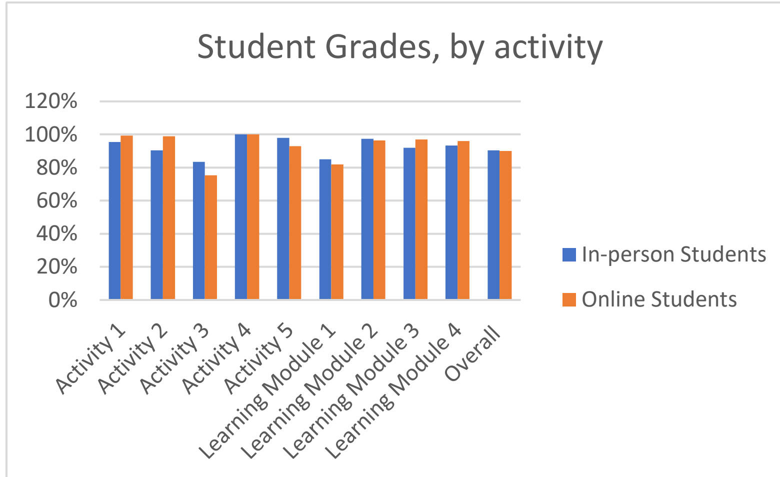

Figure 2: Comparison of grades for in-person and online students for Fall 2020

Summary of Student Feedback:

The student's satisfaction of the course continues to be very high. The enrollments are very strong for this course, with typically at least half of ME students choosing the additive manufacturing lab as their lab elective for the program requirement.

Online students were surveyed and asked to rank on a scale of 1 – 5 the level that remote learning impacted their performance in the course. A response of "1" indicated that remote learning had a significant impact on their grade and a response of "5" indicated no impact. Only one student indicated that remote learning had a significant impact; the others indicated little to no impact. The one student who indicated a significant impact provide additional insight; they noted that they struggled to manage their time and remain motivated without the structure provided by due dates in other courses.

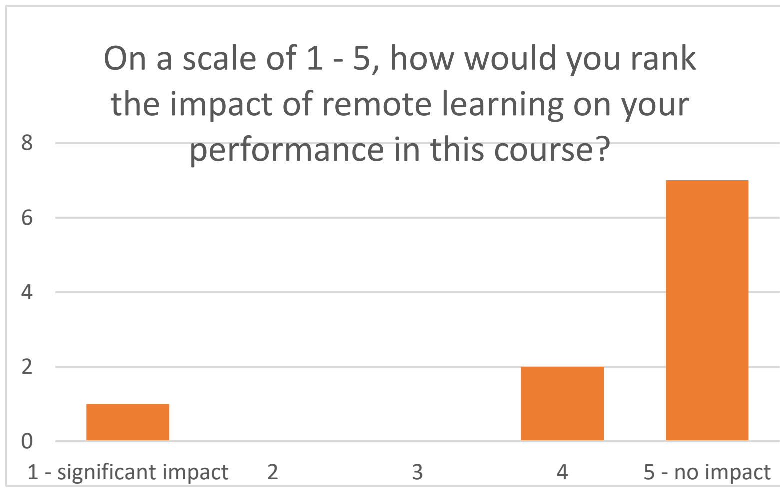

Figure 3: Results of survey question to online students

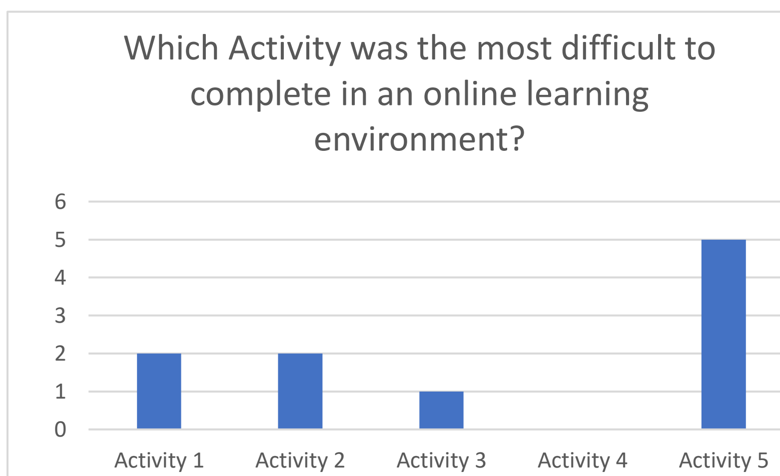

Figure 4: Results of survey question to online students

Online students were surveyed and asked which activity was most difficult to complete remotely. Responses were varied, but a majority indicated Activity 5, the 3D Scanning and Reverse Engineering activity was the most difficult. Students were asked to provide feedback on how this activity could be improved for future online learners. Feedback varied from unhelpful responses like "I don't know," or "get rid of it," to constructive ideas, such as providing students a list of apps that work and some recommendations for the types of parts that scan well using these apps. The helpful recommendations are being implemented for the Spring 2021 semester.

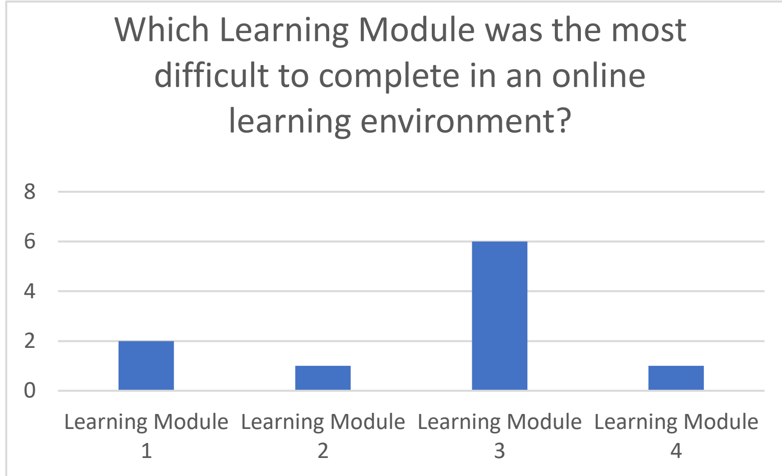

Figure 5: Results of survey question to online students

Online students were also asked which learning module was most difficult to complete online. Responses varied, but a majority indicated that learning module 3, the group research presentation was the most difficult. Students indicated that because some group members were working in person and some remotely, group work was difficult to organize. Groups used Zoom to meet and discuss the project, and work was divided up between the group members. The grades on this project for Fall 2021 indicated that despite these difficulties, the groups were still able to complete this project successfully.

In person students were also asked to rank the impact that the group work had on them for Activity 5 and Learning Module 3. Their feedback mirrored the feedback of the online students, that working in groups with online students had a minimal impact on the performance of the group and the ability to complete the project.

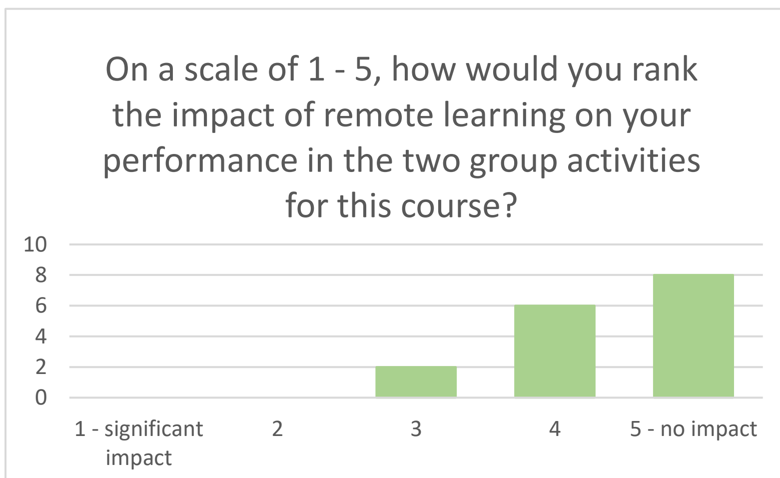

Figure 6: Results of survey question to in-person students

Each group was asked to disclose their perception of the other group. The online students were asked if they felt the course requirements were easier for the in-person students and the in-person students were asked if they felt the course requirements were easier for the online students. This question was posed as a simple yes or no question, with an optional text box to allow them to elaborate if necessary. All students surveyed answered no to their question, and no students made comments in the text box to suggest that they perceive the two groups were held to different standards for meeting the course objectives.

Conclusions:

The course instructors have concluded that the revisions made to this course have had a positive impact on both the students learning and the student's satisfaction with the course. After the first year of running the course, the course instructors felt very strongly that each student needs access to a machine to improve the quality of this course, and the decision to implement this change proved to be a necessity to the flexible learning environment during the pandemic. This new framework has also made the workload much more manageable for the course instructors because the responsibility of the repairs, maintenance, and troubleshooting has been shifted to the students. The students enjoy the course and appreciate the flexibility of the hybrid instruction approach and the flexible due dates. Students indicated increased difficulties when completing the two group projects for the course. These difficulties were attributed more to complexities in arranging group meeting when the groups include in-person and online students; the individual responsibilities required of each student in the group were not difficult to complete in a remote learning environment.

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