Work in Progress: Development of a Virtual Introduction to Machining and Manufacturing for BME Applications

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Introduction

Machining and manufacturing are essential skills that engineering students learn during their undergraduate education to prepare them for their future careers in academia or industry. Because of the unique circumstances due to the COVID-19 pandemic, biomedical engineering (BME) educators have been challenged with developing modified curricula to accommodate restrictions or prohibitions on in-person courses. The UC Davis BME introductory machining and manufacturing course has traditionally employed a hands-on approach to teach students the necessary skills needed to apply to the prototyping of their senior design projects. However, due to prohibitions on in-person instruction, the BME machining course underwent significant redesign to enable an entirely virtual offering.

Traditionally, BME seniors took this laboratory course before senior design to gain manufacturing skills and approval access to the university machine shop. During the ten-week course, they would learn how to operate the drill press, lathe, mill, and laser cutter to machine their own digital microscope using manufacturing plans given to them and watching the teaching assistant (TA) perform a demonstration. However, the virtual offering requirement shifted the main deliverables from simply machining a device to developing the manufacturing plans to machine said device. Although completing both is ideal, there is still great value in learning how to use your resources and learned machining knowledge to develop rational manufacturing plans. This is perhaps the tougher skill of the two to develop, which, if successful, will help immensely with their senior design manufacturing planning.

The purpose of this Works in Progress paper is to document our initial attempt of a complete virtual introduction to machining and manufacturing, highlight successful strategies and challenges, and provide insight on what could be improved. This is still an ongoing effort as this course is currently being taught again. The current course strategy is based on what is described in this paper, with minor improvement implementations based on student feedback.

Goals

The traditional course learning objectives were for students to (1) learn safe use of machining tools, (2) demonstrate an understanding of design for manufacturability constraints, and (3) execute manufacturing plans for a functional device. The revised virtual course objectives include the first two traditional objectives, machining and manufacturing operational knowledge, understanding technical drawings, and developing manufacturing plans. Our goal as educators is for the students to meet and exceed the objectives so that they will be prepared to safely engage with heavy machinery after a brief hands-on training once restrictions are eased. Expanding upon the new objectives, we aim to ensure students can interpret technical drawings to help develop the manufacturing plans for the microscope parts in a clear and detailed manner. In an in-person setting, students did not have to fully understand how to read the drawings since they were provided with the manufacturing protocols and watched a complete demonstration beforehand. Understanding technical drawings is a skill they will carry into their senior design projects where they are expected to create their own drawings and develop manufacturing plans. Our goal in the virtual setting is to continue to provide firsthand experience and application to enhance their learning and develop transferable skills.

Methods

In a non-virtual setting, students would be provided with engineering drawings and manufacturing plans for all the components of a digital microscope (Figure 1). Using the drawings and manufacturing plans, they would machine and build the microscope over the course of ten weeks. The machines they learned how to operate included the drill press, lathe, mill, and laser cutter. The virtual course was broken down into modules for each machine. Each module had the same workflow and structure as outlined in Figure 2.

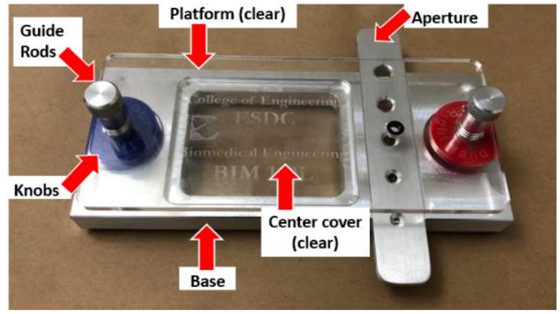

Figure 1: Digital microscope assembly. In the non-virtual setting, students would build this. In the virtual setting, students are developing manufacturing plans for the main components.

First, students were given access to instructional machine videos recorded by the Engineering Student Design Center staff and an introductory machine reading. The videos introduced the machine, its components, and covered commonly performed operations. Additionally, students had to complete a pre-lab quiz covering the key takeaways from the readings. Next, students were tasked with applying what they learned from the instructional videos and reading to develop the manufacturing plans for the relevant microscope component for that week; for example, the guide rods plans were developed during the lathe module since the lathe is used to machine those parts. For the manufacturing plan assignment, they were given all the necessary steps in random order with blanks mixed in throughout that they had to fill in. Some of those blanks were part dimensions or tool sizes that students had to refer to the engineering drawing to answer. After the assignment deadline, students would then watch the pre-recorded demonstration of the official manufacturing plan during their weekly live discussion sections. Additionally, TAs engaged students by asking them critical thinking questions to ensure they understood the manufacturing processes (e.g., why must we perform step A before step B?) and can apply what they have learned to other theoretical scenarios. Students also had the opportunity to discuss other potential applications of the machines during these live sections.

After completing the modules, students had to complete an open-note, timed exam as has been done in previous years. The questions are representative of the course objectives and material learned throughout the quarter. This exit exam was slightly modified from the year before to account for questions that students would only know if they had gotten a hands-on experience operating the machines. Because the exams are nearly identical, we can compare to the virtual setting exam results (2020) to the non-virtual results (2019). This is one method to quantitatively assess student learning. Moreover, students were also invited to complete an anonymous survey regarding the efficacy of the virtual course. The survey included seventeen questions (Table 2, appendix) using a Likert scale to quantitatively assess the effectiveness of the virtual offering. The questions inquired about the course objectives, course materials, and machine operational confidence. They were asked to rate how strongly they agree or disagree with our statements from 1-5. The survey also included short-response questions about course feedback and areas for improvement.

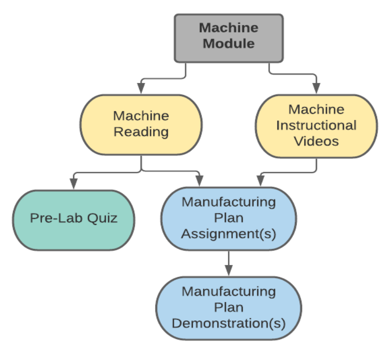

Figure 2: Virtual course module structure. The workflow for each machine module is depicted in this figure. The machines include the drill press, lathe, mill, and laser cutter.

Results and Discussion

Using the Likert scale responses from the survey (n=22), we were able to calculate the average (avg) and standard deviation (Std Dev) for every question. The averages ranged from 3.14 to

3.95, with an avg response of 3.55, all within the neutral territory; this includes the avg rating for each survey category (Table 1). The ideal response was “strongly agree”, or 5, for all questions since this would have indicated that the course was successful on all regards. However, “strongly disagree” responses would have also been helpful to identify areas of improvement. The highest scoring objectives were “Reading and understanding technical drawings” and “Learn safe use of machining tools.” Regarding the course materials, students valued the microscope demonstration videos and integrated questions, because it encouraged them to consider alternative manufacturing procedures. We are not surprised by the machine operational confidence average, because most students tend to be nervous operating a machine for the first time. However, we plan to incorporate hands-on training in subsequent courses, such as senior design. The most prevalent short-response feedback was the amount of work being too much for the number of units it was worth. This course is currently being offered virtually again, but it is now worth double the number of units to account for the amount and level of expected work. Berry received similar concerns when teaching an electrical circuits course online [1]. One student shared that they would have liked to see the microscope demonstration from the operator’s point of view (i.e., using a GoPro) to better familiarize themselves spatially with the machine and make them feel as if they are operating the machine. These are feasible ideas that could be used as supplemental material. Lastly, a few students expressed that they wish they could have taken this course in person, which echoes the results from Parkhurst et al., where students taking “Engineering Culture” in an online setting scored favorably but still prefer to take the course in person [2].

Table 1: Question categories and average responses.

Question Category	**AVG**
Course Objectives	3.59
Course Materials	3.60
Machine Operational Confidence	3.39

We also compared the exit exams from 2020 to 2019 students, virtual vs non-virtual course offerings. The 2019 avg score was 92.39% with a Std Dev of 5.92% (n=72). The 2020 avg score was 93.87% with a Std Dev of 7.75% (n=82). An unpaired t-test analysis resulted in a p-value of 0.1897, indicating that the difference is not statistically significant. These results suggest that students taking this course virtually performed similarly to previous in-person performance with respect to their understanding of machines, shop tools, and machining and manufacturing principles. It is also worth noting that the 2020 avg was over 90% which demonstrates that the students were able to learn and gain an adequate introduction to machining in a virtual setting.

Conclusions

Although still not ideal, a silver lining of teaching this course virtually has been allowing students to experience the process of applying what they have learned from general machining videos and readings to develop sound manufacturing plans for a functional device. In doing so, they would have demonstrated an understanding of how to interpret engineering drawings and design for manufacturability considerations. This innovative approach to teaching a machining course virtually is incredibly relevant to engineering education at a time when access to hands-on learning is limited by necessity. Although this course was developed solely for the purpose of accommodating in-person prohibition, it might be worth considering making it a supplemental course that BME students could take before they get hands-on machining experience. This approach has been effective for Song et al. in their specific virtual lab modules for machine tool technicians. This would greatly increase their level of confidence with operating machinery since they would already understand the machines and how to write manufacturing plans. Regardless of whether it becomes a supplemental course or not, the strategies employed may prove beneficial to implement for more long-term or permanent online course offerings.

References

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[2] R. Parkhurst, B. Moskal, G. Downey, J. Lucerna, T. Bigley, and S. Ruff, "A Comparative Analysis Of Online And In Class Versions Of Engineering Cultures," in *ASEE Annual Conference & Exposition, Chicago, IL, USA, June, 2006,* 10.18260/1-2—672

[3] X. Song, P. Pilcher, and R. Balamuralikrishna, "Virtual Laboratory For Machine Tool Technicians – Concept, Development And Examples," in *ASEE Annual Conference & Exposition, Salt Lake City, UT, USA, June, 2004,* 10.18260/1-2--13367

Appendix

Table 2. Student survey questions broken up by question category, average response based on a 1-5 Likert scale, and their standard deviation.

Question Categories	Questions	AVG	STDEV
Course Objectives	Machining and manufacturing operational knowledge	3.59	0.67
	Reading and understanding technical drawings	3.95	0.90
	Developing manufacturing plans	3.14	0.89
	Learn safe use of machining tools	3.91	0.87
	Understanding of design for manufacturability constraints	3.36	0.95
Course Materials	The ESDC instructional videos were effective in introducing each machine.	3.64	0.79
	The machine readings were effective in introducing each machine.	3.45	0.91
	The machine pre-labs enhanced my understanding of each machine.	3.36	0.85
	The microscope homework assignments enhanced my understanding of each machine.	3.14	0.94
	The microscope manufacturing demo videos were effective in solidifying my understanding of each machine.	3.82	0.73
	The overall discussion sections were helpful for my understanding of the course materials.	3.77	0.81
Machine Operational Confidence	The machine summary slides the TAs prepared were effective in learning the key takeaways for each machine.	3.77	0.87
	The microscope demo videos discussion questions the TAs prepared were helpful for my understanding of machining.	3.82	0.96
	I feel the course materials prepared me to operate a drill press in the ESDC next quarter (under supervision and brief training).	3.55	1.14
	I feel the course materials prepared me to operate a lathe in the ESDC next quarter (under supervision and brief training).	3.36	1.05

	I feel the course materials prepared me to operate a mill in the ESDC next quarter (under supervision and brief training).	3.45	1.06
	I feel the course materials prepared me to operate a laser cutter in the ESDC next quarter (under supervision and brief training).	3.18	1.14