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Continuous Improvement of an Experiential Learning Manufacturing Lab Course

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Abstract
Making up most of today's students, "Generation Z" demands learning specific and applicable methods for problem-solving. This need for application and case study-based learning stems from the wide availability of technology throughout their entire lives, making them digital natives [10,11] Experiential learning satisfies these desires and has proven to impact students' long-term learning and perceived learning [7]. In this work, a hands-on computer numerical control (CNC) manufacturing course is developed in collaboration with Autodesk Inc. to address the growing demands of Gen Z engineering students. For this course, students use a series of online videos to learn the concepts and theory of CNC machining, followed by a series of small-group, self-paced, hands-on lab assignments. Lab assignments are machined on a five-axis Pocket NC and/or a 4-axis Haas VF3 CNC milling machine. The hands-on labs are structured such that students have one "guided tour" of the CAM process followed by an open-ended assignment on the same machine and concludes with students designing and manufacturing a double-sided maze. The course is a cross-departmental collaboration between Industrial and Systems Engineering and Mechanical and Aerospace Engineering. Enrolled students come from both departments and are encouraged to form cross-disciplinary groups while working on course assignments. This work in progress paper aims to discuss the outcomes from the pilot semester, Fall 2021.

Introduction

Experiential learning is one of the most impactful methods for students to learn and retain information reaching higher achievements of Bloom's Taxonomy [1]. In conventional lecture-style courses, students are told, even persuaded, that once they've completed the basics and theory, they'll be able to learn about what *really* excites them. This approach inevitably leaves an enormous gap between understanding theory and application [2]. Developing an experiential hybrid style of course is a challenge due to the significant instructional time and the necessary physical resources (space, equipment, etc.). This work evaluates the development of an experiential lab course teaching both Mechanical and Aerospace, and Industrial and Systems Engineering students to design (CAD), program (CAM), and manufacture (machine) parts using Fusion360 and CNC machines. The design phase of this work is computer-aided design (CAD) using Fusion360. Then students develop the program for the machine using computer-aided manufacturing (CAM) tools in Fusion 360. Finally, students use the output of their CAM to manufacture the parts on the machines. This work evaluates the outcomes from a pilot semester and discusses opportunities for improvement and interventions to improve students' learning experience in the course. Future work will include comparison data from subsequent semesters.

Literature

Ubiquitous learning (u-learning) is a learning system in which "the main idea is to support learner's awareness about his/her learning situation" or, in simpler terms, anyone can learn anytime and anywhere [3, 4]. The u-learning environment can provide an interactive and seamless learning architecture that helps share learning resources [5]. When developing a new course, students must have continuous access to resources to advance their learning. Students must access both learning material and the physical space to practice the theory when teaching an experiential learning course. When students do not have the hands-on component, they struggle to transition from theory to practice [6]. In addition to physical space, students need several low-stakes assignments to practice and foster a creative and enriching learning environment. In addition, these low-stakes assignments help alleviate the tension that comes with class performance [7].

Traditional evaluation methods are challenging to implement in an experiential learning course, where the outcome of students' learning is their performance or physical parts created. Therefore, surveys are standard methods of evaluation. Pre and post-surveys are most beneficial to evaluate student learning outcomes from an assignment and measure the impact of that activity [8]. These surveys are a reflection on the student's performance as well as how impactful the assignment was to the learning outcome. Therefore, well-designed and well-placed surveys can be a beneficial and insightful tool for evaluating student performance and the course itself. In addition, using ANOVA strategies (with appropriate sample sizes) to assess significant differences in responses can identify the most and least impactful assignments. Therefore, providing a qualitative assessment of the activities [9].

Motivation
All experiential manufacturing education exists at the University of XX within the Mechanical and Aerospace Engineering (MAE) Department. The Industrial and Systems Engineering (ISE) curriculum focuses on logistics, human systems, and data analytics. In the ISE department, students learn the theory of manufacturing but lack the opportunity to have hands-on experience in design and implementation as part of the ISE curriculum. Furthermore, within the experiential manufacturing labs, there is no opportunity for students to gain experience designing for and producing parts for CNC since currently, the curriculum only provides experience on manual machines. Therefore, a cross-disciplinary course is developed to learn how to utilize and design precision subtractive machining techniques for students from both MAE and ISE departments. The course gives students in both departments the opportunity to participate in a modern, hands-on experiential learning course to apply their knowledge of manual machining and theoretical manufacturing to automated machines

The CNC Course
The CNC course piloted at the University of XX by Author 1 and Author 2 strongly emphasizes facilitating experiential learning for students. This course teaches students to use Computer-Aided Manufacturing (CAM) to make parts using subtractive automated CNC machines, including a desktop five-axis (Pocket NC), four-axis, and three-axis automated CNCs (one Haas VF3 and one Haas TM2). The course was offered for the first time in Fall 2021 with financial support from Autodesk. There are two instructors for the course (one female, one male) and one teaching assistant (female). Ten students were enrolled in the course, six were ISE and four were MAE students, six were female, and four were male. There were four lab groups consisting of two to four students. This work is presented as work-in-progress since there is only one semester of data, small enrollment, and no comparison data from other semesters. There are three components developed and evaluated in this work: (1) self-paced online learning, (2) in-class peer-to-peer learning, and (3)lab assignment effectiveness.

Self-Paced Learning: The self-paced online learning modules were completed individually using videos and activities provided by Autodesk. Students complete this work in the first month of the course to get familiar with the software, terminology, and theory of CAM. In the Fall 2021 semester, instructors did not check for completion of these online modules.

Peer-to-Peer Teaching: Each week, a one-hour class period is divided into two working periods. The first is to discuss obstacles students faced in the hands-on lab assignments that week. This allows lab groups to communicate to solve problems. The second period is student-led, and groups are given a topic to research and then present to the class. Using peer teaching exposes students to the type of research expected when working in manufacturing and provides a safe place to practice leading design discussions in their future careers.

Lab Assignments: The first lab assignment includes explicit step-by-step instructions, while each follow-up assignment is more open-ended to allow students to design with a purpose. Lab 1 consists of a step-by-step guide to design and manufacture a specific part on a five-axis desktop CNC machine (Pocket NC). Lab 2 consists of a design challenge for students to create a product with a purpose on the Pocket NC. Lab 3 tasks the students with designing and machining a double-sided maze on a 4-axis Haas VF3. Figure 1 is an example of the completed parts for each assignment.

Figure 1: (left) Assignment 1. Stock part manufactured on the 5-axis Pocket NC. (middle) Assignment 2. Student design (candle holder, it opens) manufactured on 5-axis Pocket NC. (right) Assignment 3. Two-sided maze manufactured on the 4-axis Haas VF3.

Measures of Impact

This course remains in a constant state of continuous improvement. To measure the current state and find areas of improvement, the instructors use student performance, student feedback, instructor observation, and survey data analysis.

Self-Paced Learning

There was a plethora of online resources available to students in the course; however, the instructors did not hold the students accountable to engage with the resources. It was expected that students would engage with the material due to interest in the topic. However, based on instructor observation and verbal feedback from students, many did not engage with most of the online self-paced learning material. Therefore, these resources had a low impact on learning in the Fall 2021 semester.

Peer-to-Peer Teaching

Each group completed two presentations during the semester on technical topics such as tooling, speeds and feeds, and tool paths. Based on feedback from students, they learned the most when they were developing the presentation material. However, they found it hard to absorb the information when they were listening to other groups. Based on instructor review, students did an excellent job of researching the material; however, the presentations were not interactive and felt rushed. The lecture portion of the course was offered online. This was in part due to the COVID-19 pandemic but also for convenience. Based on survey results students felt they needed more in-person lecture time (figure 2). Therefore, peer-to-peer teaching had a medium impact on learning in Fall 2021.

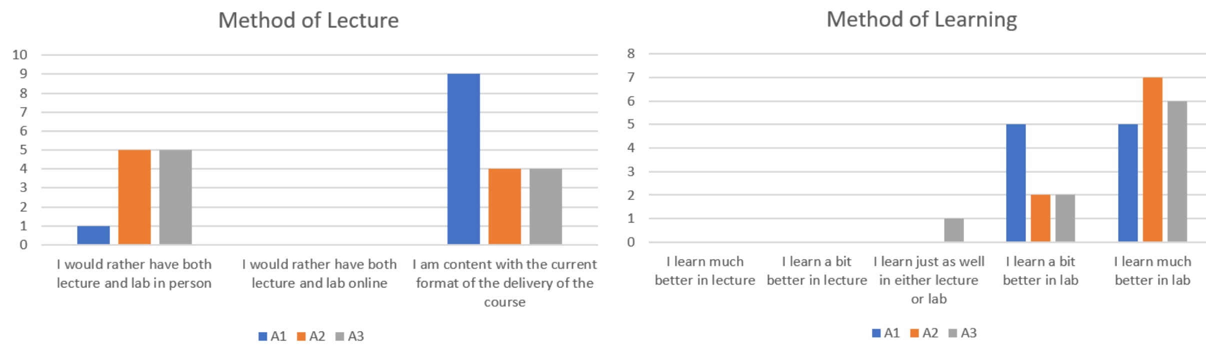

Figure 2: (left) Preferred method of lecture. (right) Self-assessed environment students felt they learned the most information.

Lab Assignments

There were three overall assignments. All four groups designed and manufactured the stock part and their designed part successfully on the desktop five-axis machine (assignments 1 and 2). Three groups manufactured a double-sided maze on the four-axis Haas VF3 (assignment 3).

After each assignment, a survey was distributed to the class, totaling three surveys. Students were also asked about which environment they felt they learned CNC concepts better. There was a trend that students felt they gained the most knowledge from lab time instead of lecture (figure 2). Students self-assessed their knowledge of CNC principles before each assignment. Based on this question, we observed a trend of increasing knowledge, although there is no statistical difference. This indicates that students felt they were gaining more knowledge of CNC principles with each assignment (figure 3). Students were also asked to assess how beneficial each assignment was to their learning. Here we observe a trend that students felt each assignment was more beneficial to their learning (figure 3).

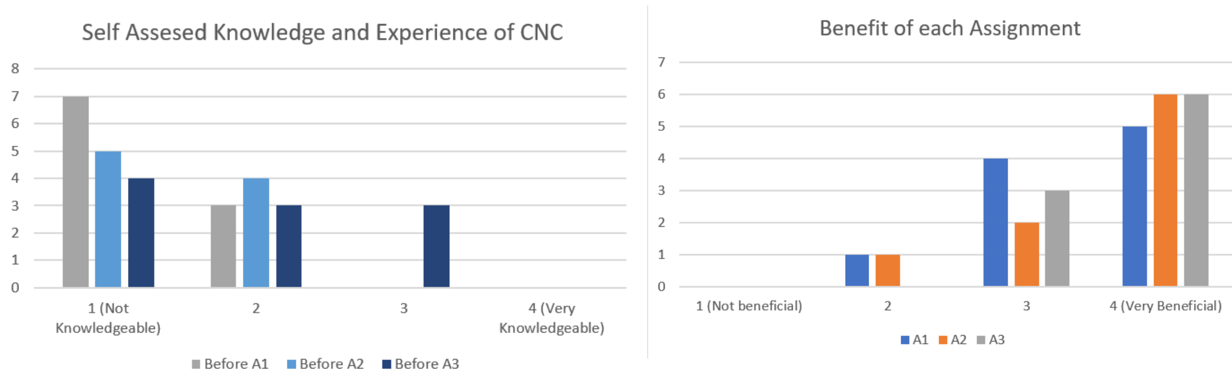

Figure 3: (left) Results of students' self-assessment of CNC knowledge before each assignment. (right) Results of students' assessment of each assignment impact to their gain in knowledge.

The survey also asked students to provide open-ended feedback on each assignment to provide constructive criticism. We address some of the common themes here. The first assignment (stock part, 5-axis) was too guided, and students didn't feel they learned "why" only "how" to CAM this specific part. This escalated into the second assignment (design part, 5-axis) when they had to design a part and create the tool paths. There was a gap in knowledge between the assignments, causing the second assignment to take much longer than anticipated. In the third assignment (two-sided maze, 4-axis) students were ill-prepared to work on the machine. Although students went through a 2-hour training, they were not prepared to design, CAM, or manufacture on the large 4-axis Haas VF3. This led to some safety concerns as well as an extended time to complete the assignment. One group did not complete the assignment due to their complications on assignment 2. Therefore, the assignments are considered to have a high level of impact on students learning but need significant improvement.

Discussion

The students' overall attitudes were positive at the end of the semester. In addition, students verbally expressed their excitement about the course and everything they learned. However, several changes have been made for the Spring 2022 semester in response to the results above.

Self Paced Learning

The instructors now monitor the online resources. Students must submit the certificate of completion as an individual graded assignment. More online resources regarding safety with CNC machines have been added, and individual follow-up assignments are required and graded. These were established to hold students accountable to engage with the provided online resources, and we expect that adding these requirements will make students more prepared in the lab. Therefore, assignments can be completed more quickly, and we plan to include a project in the last month of the spring 2022 semester.

Peer to Peer Learning

Students in the pilot semester felt it was hard to absorb information during lectures and indicated they learned the most in lab. Therefore, in the Spring 2022 semester, the lectures are in-person and instructor-led. These lectures cover the same material but are designed to be active/discussion lectures. Since the instructors have more experience in developing these types of lectures, we expect to see greater satisfaction with the lecture portion of the course.

Lab Assignments
The instructors also observed that since students spent so much time on the desktop machine's first two assignments, the transition to the larger VF3 machine was not unstable. Therefore, the assignments were restructured so that assignment 1 remains a stock part on the desktop machine, assignment two is a stock part on the VF3, and assignment 3 remains the two-sided maze on the VF3. We have also added more standardized training among groups and a "live assessment" where students must perform five steps, including setup, tool change, probing stock, machining a part, and shut down as a group. They are assessed using a rubric. Groups must pass the live assessment to move past assignment three to the project part.

Students in the pilot semester indicated several opportunities for improvements, including using the first assignment to learn more about the CAM process and more training and experience on the Haas VF3. Therefore the following changes have been implemented on the lab assignments.
Changes to Assignment 1: The Pocket NC assignment was altered to allow students more independence in the assignment. Instead of a step-by-step CAD and CAM guide, the students were provided with a technical drawing and led through the CAM process with their instructors during their lab time. Seeing that the students come in with a significant level of experience using CAD software reduced the time necessary for the CAD process. It allowed the students more time to explore the CAM process during lab time.
Changes to Assignment 2: A new assignment was created to introduce the students to the 4-axis machine and to allow them to explore machining from a given stock part. Students are provided the part file, tools to use, and some hints for the CAM process. They complete the CAM process as a group and learn to set up the machine for use independently.
New VF3 Live Assessment: A second training step was added to the initial training for the Haas VF3 – an unguided live assessment. After training, students are assessed on their ability to safely operate the Haas VF3 through every step of its operation. They learn to change and probe tools, probe material and navigate the Haas workspace.
Changes to Assignment 3: Students would no longer learn the VF3 on this maze assignment due to the implementation of assignment 2. We expect students to complete the maze in about three weeks compared to the six weeks it took students to complete it in Fall 2021.
Project Assignment: Due to the changes mentioned above and based on the pace of the groups so far, we expect to have 4 weeks at the end of the semester dedicated to a project part. Students have the freedom to use the desktop 5-axis or the 4-axis VF3. The part they manufacture can be for a design team, a special project, or something they want to make. The parts will be vetted and reviewed by instructors.

Based on the experience from the pilot semester in Fall 2021, and the outcomes from student feedback, the team is implementing the above changes to the Spring 2022 semester. So far, the implementation changes have been well received by the students. However, there is no data analysis on the Spring 2022 semester survey results due to the time this work was written. We hope to continue this work, gain more insight for future course updates, and provide best practices to other instructors developing similar courses.

Future Work

We will proceed with the continuous improvement efforts in the Spring 2022 semester. Surveys are deployed after each assignment and will be evaluated in a similar manner to the work in progress presented here. We will also evaluate for statistical differences in the groups based on the changes made to the course in Spring 2022. We will continue to identify ways to improve students' learning experience in the experiential CNC course. The team plans to submit a full paper to the Manufacturing Division in 2023.

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