WIP: Is it possible to have individual student machining projects at a large state university?

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Scott Kiefer has spent the past twenty-five years teaching mechanical engineering at five different colleges. He started at the University of Puerto Rico at Mayaguez in the traditional role of teaching and administering a modest graduate research program. At Trine University, a small private school in Angola, Indiana, he focused on undergraduate education while teaching ten different courses ranging from introductory freshman courses to senior capstone. Scott also served as an advisor to many different undergraduate research projects. He then moved on to Michigan State University and took a position as a teaching specialist concentrating on undergraduate classroom instruction. Scott then moved to York College of Pennsylvania where he spent thirteen years teaching all levels of mechanical engineering and helped countless students manufacture projects in the machine shop. He is now at North Carolina State University and hopes to be able to add more machining and hand-on experiences to the Mechanical Engineering Curriculum.

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Abstract

While working as a mechanical engineer does not necessary require that a person have machining experience, the case has been made by industry and academia that a good mechanical design engineer needs to have understanding and experience that can best be obtained from completing projects in a machine shop. The authors of this paper have had good success in implementing student machining projects in a course at a small private college, and have included some of the assessment data in this paper. The machining projects included individual student projects using both a manual and CNC mill and lathe. The course concentrated on machining tolerances, and also included CAD work to improve communications with shop personnel. The cohort size was usually around 50-60 students distributed among three sections. One of the authors would now like to implement the same type of projects at a large state university with a cohort of close to 400 students. This project is currently in the planning stages, and the authors are presenting it as a work in progress. The main focuses of the project at this point are class structure and scheduling, TA organization and training, and development of course outcomes and assessment.

1. Introduction

Over ten years ago, York College of Pennsylvania, a small private college, determined that it would try to improve the mechanical engineering program by adding hands-on machining experiences early in the curriculum. Alumni and industry surveys had identified that some graduates of the program lacked knowledge in machining methods and how they influence engineering design. In addition, graduates were not always able to demonstrate how machining tolerances should be correctly applied to ensure quality and reduce production cost. Finally, it was recognized that graduates of the program could use some improvement in the quality of the engineering drawings they produced. It was decided at that time that a course should be added to the freshman year curriculum specifically for hands-on machining projects and advanced CAD work. The class included individual projects for the students to build in the shop, and CAD assignments designed to improve understanding of engineering drawings and tolerances. The machining course was determined to be successful through industry and alumni feedback, student evaluations, student performance in higher level courses, and personal observations.[1]

The instructor most responsible for the development and implementation of the machining course has now moved on to North Carolina State University. Because of the benefits the students received at York College, the instructor would like to try to include machining projects in a course at NC State. The most noticeable obstacle will be serving 350-400 students per semester, as opposed to 50-60. The adaptation of the machining projects is currently in the planning stages. Therefore, this paper is being presented as a work in progress. At this stage, the authors will be presenting possible class scheduling, TA organization and training, and possible assessment of the projects.

2. Machining Class at York College of Pennsylvania

The machining class at York College typically had between 20-24 students. To avoid having too many students in the shop at once, the class was split into two groups. Half of the students worked in the computer lab with the instructor of the course on some advanced CAD work, while the other half worked in the shop on the machining projects with the shop supervisor. After a three-week cycle, the groups switched. This allowed for four, three-week cycles in the semester with time for exams. Each group of students had two cycles in the shop and two cycles in the computer lab. The shop cycles included one milling project and one lathe project. Each machining project included both manual and CNC machining.[1]

As an aid to the shop supervisors, the group of students in the shop was given a project booklet with detailed step-by-step instructions (figure 1). In addition to the step-by-step instructions, the booklets also contained finished detail drawings with proper tolerances for the students to reference. The booklets allowed students to work at their own pace, getting help from the shop supervisors when they had questions. With the booklet in place, the shop supervisors only needed to give a 15-20 minute demonstration of each machine (mill or lathe) the first day before the students begin machining. As each student progressed through the project, and needed to develop the G-code for the CNC part of the project, they would go back to the computer lab where the course instructor was teaching the advanced CAD work. In the computer lab, students were also given set of detailed, step-by-step instructions so that they could work independently developing their G-code and ask questions when they had problems.[1]

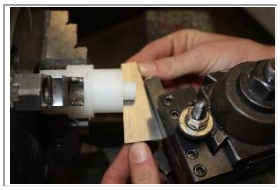
	You are now ready to cut the angled surface. We will change tools to make this cut. First, place the right angle cutting tool in the tool post. Then loosen the large nut on the top of the tool post to allow us to change the angle of the tool.	
	Lay a 14° gage block against the work piece and move the tool post until the tool is flush with the edge of the blocks. Then, tighten the large nut to lock the tool holder in place. Recheck the angle after tightening to make sure the tool didn't move.	
	We now need to zero the Z direction for the new tool. With the lathe stopped, slowly move the cutting tool until its left edge just meets the faced surface you just cut. (Some machinists like to put a piece of paper between the tool and the work piece. When you cannot slide the paper, you are 0.003" away from the part.)	

Figure 1: Example of Manual Machining Instructions for the Lathe Project

3. Machining Projects at York College of Pennsylvania

The milling project used in the machining course was a version of a project that has been around the machining world for years. It is simply a spinning and sliding mechanism that has no practical function, but it is an excellent example of why you need to hold good tolerances. The project is shown below in figure 2.

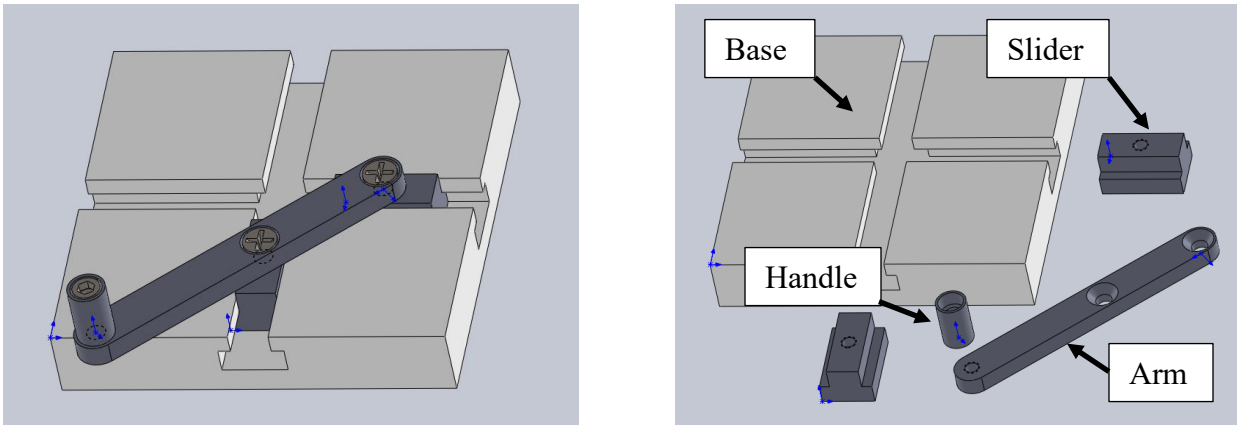


Figure 2: Slider Project Created Using Manual and CNC Milling Machine[1]

The lathe project that was used in the machining course was a version of a soft-blow hammer. It included two threaded, plastic tips that were inserted into a counterbored aluminum head. The handle was also threaded and countersunk into the head. The hammer project is shown below in figure 3.

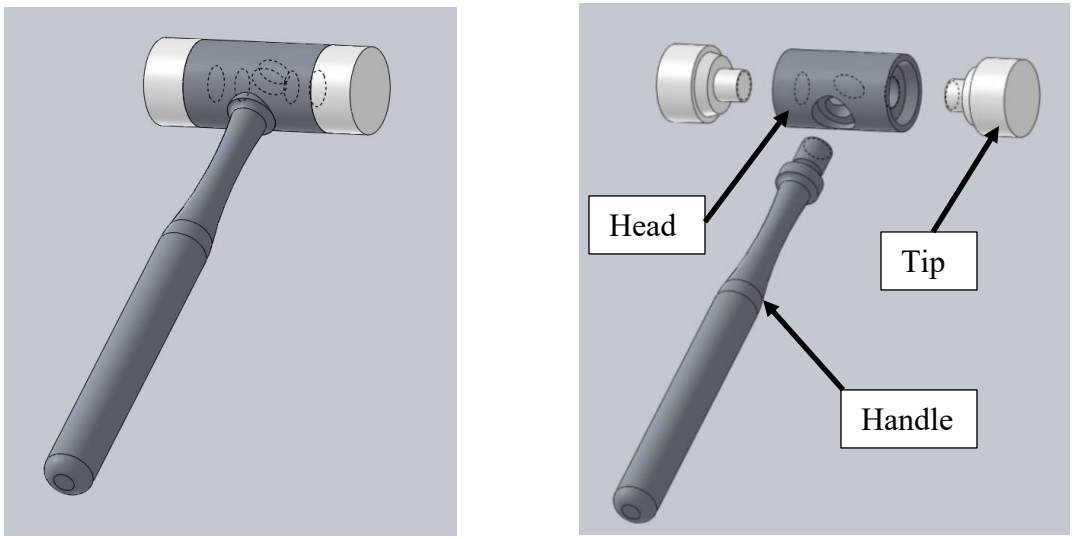


Figure 3: Hammer Project Created Using Manual and CNC Lathe[1]

4. Assessment of Machining at York College of Pennsylvania

To assess the value of the machining projects at York College, industry feedback was collected from a broad range of companies to determine if the projects were covering the correct content. The industry feedback first asked the importance of including machining activities in a mechanical engineering curriculum. It then expanded to detemine the amount of time that should be devoted to machining activities, and finally determined what type of machining skills were most important.

There was an overwhelming response from industry feedback that maching skills were important to a mechanical engineer. All but one company indicated it was "very important" or "somewhat important" for mechanical engineers to have machining experience. Furthermore, well over half of the respondents stated that there should be at least one course in the Mechancial Engineering Curriculum dedicated to machining skills. Many respondents suggested that more than one course was necessary.

With the benefit of machining skills to industrial employeers established, employeers were asked to clarify what machinging skills were most important to their mechancial engineers. Using a lathe and a milling machine were the clear leaders. Noticeably behind, but still making a showing, were welding, 3D printing, and working with sheet metal.[1]

The machining class had been taught at York College for over 10 years. Student feedback had always been among the highest in the department, and had included good suggestions that were able to be implemented to improve the machining experience for the students. The course had unquestionably given students more confidence in the shop and their ability to create machined parts. While not specifically measured, student machining ability was apparent in projects the students built in a machine design class in their junior year, and in their senior capstone projects. The survey information from alumni and local companies that orginally suggested this course was needed was still collected. However, it no longer contained comments about students needing more machining knowledge, having problems working with tolerances, or understanding working drawings.[1]

5. Benchmarking Other Universities

Every school with a Mechanical Engineering Program has a machine shop, and most are very well equipped. However, there are very few universities that require machining in the lower-level mechanical engineering classes and have made an effort to teach machining skills to all mechanical engineering students. Most programs do not have students in the shop until senior design, and students often do not touch the machines until after their design work is complete (if they use the machines at all).[2] There are a few exceptions.

San Jose State University has machining required in their lower-level mechanical engineering classes. San Jose State requires mechanical engineering students to take a course (ME 41) in the fall of their junior year that requires them to learn shop skills and do some manual machining. This is a lab course that meets once a week for a three-hour block of time, and they serve around 200 students each year. San Jose State has a maximum of 18 students in each lab section. After completing the required class, students have the option to take an additional elective course (ME 42) to do some advanced project work in the shop.[3]

The University of Massachusetts Lowell has a required course sequence that all underclassmen in mechanical and industrial engineering take (MECH.1100 & IENG.2100). The first course is taken in the freshman year and focuses on technical skills (learning to use a manual mill and lathe). The second course is taken in the sophomore year and includes design and project work, along with some advanced CAD work and machining necessary to support a project build. The UMass Lowell courses serve around 200 students per year in mechanical engineering. The first course (MECH.1100) is a one-credit course that meets for one hour each week. The second course (IENG.210) is a lecture/lab course and includes one hour of lecture and one two-hour lab each week. The lab sections are limited to 24 students.[4]

Purdue has found an interesting way to use a machining activity to help bolster school pride. In their sophomore year (ME 264 class), students are required to use a lathe and milling machine to make a hammer similar to the one their mascot carries. Approximately 600 students take this course each year and it is broken into a one-hour lecture session and a three-hour lab session each week. There are a maximum of 20 students per lab section.[5] To support the machining activities, Purdue hires undergraduate students as lab assistants. They have developed an extensive training program for these lab assistants. At any one time, there are over 30 students at various levels of training that are used to support the machine shops. This allows them to have 2 or 3 lab assistants for each group lab section of 20 students.[6]

The University of Michigan uses a two-course sequence to require that all mechanical engineering students have machining experiences, without specifically allocating class time for the activities. Students take Design and Manufacturing 1 (ME250) in their sophomore year. In this course, each individual student is first required to complete 5 out-of-class, online modules covering general shop safety, cutting and drilling, milling, lathe use, and precision measurements. Once the online modules are complete, each student signs up for shop time to complete one prescribed milling project and one lathe project outside of scheduled class time. Finally, the students are required to machine projects of their own design in project groups. Once again, they sign up for time in the shop outside of class to complete the projects.[7] After completing ME250, students take Design for Manufacturing II course (ME350). Since the students all have experience machining in ME250, ME350 requires them to build a prototype of a project that they develop in design groups, and once again sign up for time outside of class to complete the projects.[8] The ME250 and ME350 courses typically serve about 150 students per semester.[7]

The Ohio State University is another school that requires machining in the mechanical engineering curriculum. Students are required to take a class (MECHENG 2900) in their sophomore year that includes a one-hour lecture session and a two-hour lab session each week. The course covers basic shop skills and manual machining. It serves about 275 students per year, and the lab sections are broken down into groups of 15 students. Once students have completed this course, they are allowed to attend open shop hours and use the machines to work on projects for other courses. They also have an option to take a senior level elective course that covers CNC machining.[9]

Universitas Negeri in Yogyakarta, Indonesia has included machining in their mechanical engineering curriculum at the freshman level. They have also conducted research to evaluate the needs of students in a machining course. They found that having the right equipment available to students was the most important part of being successful in including machining in a mechanical engineering curriculum. Having experienced supervisors and well-trained

technicians assisting students was also very important. Finally, they found that having electronic media options available for students to reference when completing machining projects was also very beneficial.[10]

While Mechanical Engineering Programs that require machining in their lower level classes are in the minority, most of the schools that offer Mechanical Engineering Technology degrees do have required machining courses in their technology degrees.[11,12] In addition, there are schools that have required machining courses if students choose a specific concentration within the mechanical engineering degree. For example, the University of North Carolina at Charlotte requires students to take a sophomore machining class if they choose the Motorsports Emphasis within Mechanical Engineering.[13]

6. Adding Machining Projects to a Lower Level Class at NC State

There are many different ways that universities have found to include machining experiences in their curriculums. Some have stand-alone courses (usually 3 credits) that concentrate on machining and CAD work.[1,3,10] Others have separate lab sections that concentrate on machining projects to supplement larger lecture classes that concentrate more on design.[4,5,9] One university even has required shop activities where students sign up to complete projects in the shop outside of class or lab time.[7] There does not seem to be any one best practice for how to include machining experiences in a mechanical engineering curriculum.

There is currently an Introduction to Mechanical Engineering (MAE200) course in the curriculum at NC State University that will be able to include machining activities without having to go through the curriculum revision process. Therefore, using MAE200 does remove one possible hurdle to the addition of the machining projects. However, using this course does impose some limitations. It is a one-credit course, so the most time that can be allotted for it is one three-hour lab session per week. In addition, MAE200 uses PhD students as teaching assistants to run all the lab sections. Currently none of the PhD students that are assigned to the course have any machining experience. As noted by the Universitas Negeri, having well-trained instructors is crucial to the success of the machining experiences.[10]

For the foreseeable future, the number of mechanical engineering students per cohort at NC State is projected to be about 400, so the MAE200 course will need to service that many students each year. Because of shop space limitations with Senior Design, most of those students will need to come through MAE200 in the fall semester when Senior Design is concentrating on design. Many of the larger universities evaluated had larger sections of lower-level students working in the machine shop in semesters off-set from the major use of the machining equipment in Senior Design, [3,6,9] so this seems like a workable situation.

7. Class Size and Personnel

Most of the universities surveyed had lab sections of 20-25 students in the shop at one time, with a shop supervisor and two or three student lab assistants.[3,4,7,9] While this seems to be the most common configuration, something a little different is going to be first implemented at NC State. Because the MAE200 course is currently used to support PhD students with teaching assistantships, they will need to be included. Therefore, the class will be scheduled as a lab class with 28 students. The class will then be broken into two groups of 14. The first group will be in

the shop for the first half of the semester with a shop supervisor and one lab assistant who has machining experience. The second group will be with a PhD teaching assistant working through some classroom activities including things like how to create good drawings with proper tolerances and thread callouts. This is similar to the model used at York College,[1] and will accommodate the use of the PhD teaching assistants.

8. Scope of Machining Projects and Instruction

Of the universities examined, it seemed like each machining project was typically taking 12-18 hours for students to complete.[1,3,7] With the proposed schedule, students at NC State will have approximately 19 hours in the shop. Therefore, the MAE200 course will start out with only one machining project per semester. If it seems like there is more time, another project can be added later.

Based on the industry response to the original class at York College, the milling project would be the most beneficial for students.[1] Because the instructor has used the slider milling project (shown in section 3, figure 2) in the past, it will again be used in MAE200. This project will complement the instruction the TAs will be doing on tolerancing.

As noted by the research at Universitas Negeri,[10] having well trained instructors is crucial to the success of machining projects. Therefore, as done at Purdue, undergraduate students with prior machining experience will be hired as lab assistants[6] and media demonstrations will be created. A shop supervisor and trained lab assistant will be assigned to each section of MAE200. They will demonstrate how to complete the various steps of the project for the students in real time. In addition, video demonstrations will be recorded and linked to QR Codes on each machine so that students can review how each step of the project should be completed through the videos if an instructor is not available. The video instruction will also be available on the course web page so students can review the material before coming to the shop. Booklets similar to those used at York College will also be created so that the students can follow written instructions if they prefer.

9. Scheduling

To further ensure that lab assistants are well prepared, the first week of the semester will be used specifically to familiarize the lab assistants with the project the students will be completing. The lab assistants will use that first week to each make the machining project themselves with the support of the shop manager and course instructor. Also, during the first week, the PhD teaching assistants will go through the lab activities they will be instructing. The students will then report to class the second week of the semester. The lab assistants will be ready to demonstrate each of the steps of the machining project to them, and the teaching assistants will be ready to lead them through the course labs. At the midpoint of the semester, the student groups will switch and process will begin again.

Activity	Week
Lab assistant training	1
Machining Project / MAE 200 Labs	2-8
MAE200 Labs / Machining Project	9-15

Figure 4: Lab Schedule

To service 392 students, there will need to be 14 lab sections of 28 students each. Working with the available university class times, the following course times could be offered.

Day	Time
Monday	8:30 – 11:15
Monday	11:45 – 2:30
Monday	3:00 – 5:45
Tuesday	8:30 – 11:15
Tuesday	11:45 – 2:30
Tuesday	3:00 – 5:45
Wednesday	8:30 – 11:15
Wednesday	11:45 – 2:30
Wednesday	3:00 – 5:45
Thursday	8:30 – 11:15
Thursday	11:45 – 2:30
Thursday	3:00 – 5:45
Friday	8:30 – 11:15
Friday	11:45 - 2:30

Figure 5: Lab Meeting Times

10. Equipment Needed for Machining Projects

To ensure success, it is important to have machines available that inexperienced students can easily learn to use. Both the machines used at Ohio State[9] and York College[1] were made by Tormach.[14] These milling machines are easy to use for someone who is not very experienced in CNC machining, and they can also be used in manual mode with a hand controller.[14] If the students are put into groups of two, seven mills will need to be available for fourteen students (half of each lab section). The milling machines are approximately $35,000 each including the basic tooling needed to get started.

11. Course Assessment

The original course assessment at York College showed that the machining course was successful.[1] The assessment of the new machining experience will attempt to determine if the students at a large state university can be provided with a similar experience and be just as successful. There are over ten years of course evaluations available from students at York

College. After establishing the new machining projects at NC State, the same questions from course evaluations at York College will be asked of the students at NC State for comparison.

In addition to the standard course evaluations, a new student survey will be administered to students with questions that will be asked at both universities. The goal will be to determine if the student experiences with machining projects differ at different sized universities. Specifically, the surveys will be used to evaluate the effectiveness of the undergraduate lab assistants in comparison to more experienced shop supervisors. Also, the length of lab time available and frequency of course meetings will be evaluated.

In addition to student data, local industry partners' input will be considered in the assessment of the new machining projects. The Senior Design projects at NC State are supported by local companies. Most of these companies have sponsored senior design projects for many years. Once students who have completed the MAE200 machining projects reach Senior Design, the industry contacts will be personally interviewed and surveyed to determine if the quality of the designs and the prototype builds have changed with the machining experience added to the curriculum. In addition, questions from the survey given to the industry representatives at York College will be asked of the NC State corporate sponsors to determine the importance of machining to local industries and to verify what kind of machining activities they deem to be most important.

12. What's next?

The preliminary steps necessary to implement the machining projects in MAE200 have been taken. The course modifications are approved. The new course schedule, the hiring of lab assistants, and the use of graduate teaching assistants have all been approved. A general set of course outcomes has been created, and a project has been chosen to support the outcomes. Space has also been allocated for the new milling machines that are needed to service the course.

The first big challenge will be to get the funding approved to purchase the new milling machines. Some money will come from the Mechanical Engineering Departmental Budget and some from the Dean's Office. The goal is to get enough funding to purchase two machines in the first year and four more in the second year. If the first two machines can be ordered in enough time to get them set up and working over the summer, the machining projects will be implemented in one or two sections of MAE200 in the Fall Semester. This will provide a small trial to work out some of the bugs before expanding into all the sections of the course. The long term goal is to get the additional machines in over the following summer and to offer the machining projects to all sections of the course by Fall 2027.

Once the machines are ready to go, there are some other smaller details that will need to be worked out. The video instruction and written booklets will need to be produced using the new machines. Storage racks will need to be constructed to store the raw material necessary for the projects. Tooling will also need to be obtained and organized so the students have easy access to what they need to complete their projects.

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