



## Machining Experience in a Mechanical Engineering Curriculum

**Dr. Scott F. Kiefer, York College of Pennsylvania**

Scott Kiefer has spent the past thirteen years teaching mechanical engineering at four institutions. As an exemplary teaching specialist in mechanical engineering at Michigan State University, Scott received the Withrow Award for Teaching Excellence, given to one faculty member in the College in Engineering for outstanding instructional performance. Scott specializes in machine design, vibrations and controls, and mechatronics. He started his career at the University of Puerto Rico at Mayaguez in the traditional role of teaching and administering a modest research program. At Trine University, a small private school in Angola, Indiana, Scott taught ten different courses from introductory freshman courses to senior design, while serving as advisor to many undergraduate research projects. For the last three years, Scott has been at York College of Pennsylvania where his concentration is on undergraduate education in mechanical engineering.

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## Abstract

Can a student become a good mechanical engineer without ever walking into a machine shop? The answer to this question may be that it is possible. However, this paper makes the argument that a good design engineer needs to have understanding and experience that can best be obtained in a machine shop. Better mechanical designs will be created by a designer with the complete understanding of how machine components are communicated through mechanical drawings, dimensioned and toleranced, and finally created in a machine shop. Furthermore, this paper explores how project builds should be included throughout the curriculum so that every student gets the appropriate exposure to the proper machining experiences to hone their mechanical design skills.

Most mechanical engineering programs have three logical places where machining experiences can be very effective. First, many schools have a freshman design experience that focuses on outcomes such as the important aspects of teamwork, communication skills, and lifelong learning. Unquestionably these are very important skills and they fit well in the freshman year. However, these skills can easily be incorporated into projects that focus on the machining experience giving students the basic understanding of manufacturing that will make them better mechanical designers in the future. The basic machining and drawing documentation skills learned in the freshman year can then be applied to a junior level mechanical design course that incorporates a design, build, and test project. Students will then be ready to apply design analysis to create simple devices that they can manufacture in the machine shop. Finally, a capstone course will naturally make use of manufacturing skills.

Assessing the importance of including machining and design documentation experiences in the mechanical engineering curriculum for all students was substantiated with student and alumni feedback and with data from local industries. Specific examples are given of student project work, industry feedback, and course outcomes.

## 1. Introduction

This paper provides the history of how and why machining, detailing drawings, and tolerancing are being incorporated throughout the Mechanical Engineering Curriculum at York College of Pennsylvania. It begins with the historical reasoning behind the implementation. This is followed by the implementation strategy and some preliminary assessment of the effectiveness of machining and drawing documentation activities.

## 2. Historical Background

From its inception, the York College Engineering Program has always prided itself on being a “hands-on” engineering program. Lab experiences are used heavily throughout the academic curriculum to reinforce lecture material. In addition, there is a freshman level project oriented course sequence, and a two-semester senior capstone course that includes a large project build<sup>1</sup>. However, based on both co-op employer<sup>2</sup> and alumni feedback<sup>3</sup>, there are some simple

enhancements that could be included to make the program better. Students are not getting a complete understanding about the processes of machining something with the correct tolerances to insure proper fit and function. They also have problems properly detailing and interpreting engineering drawings. In general, they need more experience in completing the details of their designs and a better understanding of how they will be created.

## **2.1 Feedback from Co-op Employers and Students**

The York College Mechanical Engineering Program has a mandatory co-op program where each student is required to complete three co-op terms before graduation. In order to insure the quality of the co-op experience and monitor the students' performance, faculty members visit each student at the site of their employment. Both students and engineering supervisors are interviewed during these visits. Several of the interview questions are constructed to determine the quality of the students' academic experiences and identify areas where the curriculum could be improved.

Over a five year period, the most frequent responses to the questions about curriculum improvement pointed out two areas that could be improved<sup>2</sup>. First, students need a better understanding of how things can be manufactured. Specifically they are lacking a complete understanding of the machining process and how it influences design. Second, students do not have a complete understanding of proper dimensioning and tolerancing. They often do not even realize how they can affect cost and production time. These two areas of suggested improvement are mentioned far more frequently than any other response by both students and employers at the co-op interviews.

## **2.2 Feedback from Alumni**

Feedback about the engineering program is collected from alumni in several different ways at York College of Pennsylvania. First, as part of the ABET assessment plan, formal alumni surveys are conducted to collect data from alumni five years after graduation. These surveys include questions about improving the program. Alumni are also invited back to campus several times throughout the year. An Industrial Advisory Board dinner brings them back every spring where conversations often arise about additions they would like to see in the curriculum. In a more formal setting, they are also asked to evaluate student Capstone Design presentations at two different times during the year.

Throughout all these methods of collecting feedback, the same two points arise most often. The biggest improvement that alumni would like to see in the engineering curriculum is a better understanding of machining and a better understanding of dimensioning and tolerancing. While these are skills that most alumni have learned while at their jobs, they feel the program could have better prepared them while they were students.

## **3. Benchmarking**

Because the message seemed to be clear from alumni and industry representatives, a quick search was done to determine what other schools were doing with respect to machining and tolerancing. The first clear message was that some schools were not doing anything. After searching through many curricula and interviewing alumni from many different schools, a good

summary response came from someone who was currently running his own consulting firm. He stated, “I was so disappointed. After four years of engineering school, I wasn’t able to create anything. I couldn’t accomplish what I went to school to learn how to do. I had to learn what I needed to know on the job.”<sup>4</sup>

It was also clear that some schools have recognized the benefits in offering their students machining experiences. Currently, there are courses that include CNC machining in the curriculum at Purdue, San Jose State, Michigan Tech, the University of Alabama, and the University of North Carolina at Charlotte. A quote that summarizes many of the students’ responses who have had machining experience was best posted on a blog dedicated to young engineers. The post read, “Before embarking on my college career, I got a one year diploma in machining at my local community college. Best thing I ever did. After that, I worked for a company doing machining work. This experience has been so valuable over my engineering career. It made many of my engineering classes easier because I knew what was going on and why it was done that way.”<sup>5</sup>

#### **4. Implementation Strategy**

Since the evidence was clear that machining, detailing drawings, and tolerancing should be better represented in student coursework, an implementation strategy was adopted to give them a stronger presence in the curriculum. First, a junior level course in machine design was adapted to require the design, fabrication, and testing of a simple device. Observations from this experience were then used to enhance a freshman course sequence that was currently being used to introduce students to engineering. Finally, the capstone design course would be evaluated to determine if additional enhancements were required to give students the experience and understanding that employers and alumni were looking for.

##### **4.1 Machine Design Course**

To incorporate machining and tolerancing in the machine design course, a semester long project was used<sup>6</sup>. The project was simple enough in nature that it could be completed in parallel with weekly homework assignments and exams. However, it required the students to build, test, and properly document their design. For example, the first project that was used required the students to design a tabletop device to extract juice from apples. Analysis was required to minimize the size and weight of the device, and a complete CAD model was required before construction was to begin. The project was done in groups of three students, and a peer evaluation was used at the end of the semester to adjust grades according to individual contributions. The class size was about 25 students, and a technician was available in the shop for 28 hours per week during the build phase of the project.

Prior to the machine design course, the students had been given about seven weeks of CAD instruction using SolidWorks and had constructed a basic project during the freshman introductory course sequence. However, the freshman projects were aimed at giving an introductory experience with a combination of Electrical Engineering and Mechanical Engineers. Most of the construction consisted of two by four frames being held together with wood screws, and none of the projects required any engineering analysis. Very little attention was given to tolerances or machining skills during the freshman course instruction.

The machining and tolerancing abilities of the students were assessed at two different times during the machine design course. First, each design group was asked to prepare for a design review at the midpoint of the semester. At this time, their mechanical analysis was to be complete and they were asked to prepare for a ten minute meeting with their “project supervisor” to defend their design decisions and present a plan for fabrication. These meetings were attended by both the course instructor and the shop technician. The students were given immediate feedback as to their design, proposed machining methods, and if they had considered the proper tolerances. The second assessment came at the end of the semester. The students were required to submit a final written design report including properly toleranced drawings and give a ten minute oral presentation including all stages of product development. During the oral presentations, they were asked very pointed questions about their shop experience and what they had learned about design and manufacturing.

The machine design projects were a very good first step in improving the students understanding of machining and choosing proper tolerances. The comment that resonated most with all of the design groups was best made by one of the students in the first oral design presentation, “Just because you can draw it in SolidWorks, doesn’t mean you can build it.” Another common lesson learned was that very careful machining was required if things were going to fit together well and function as intended. Most students were also very surprised at how much more time it took to build their projects than they originally anticipated.

While the students learned valuable lessons from the machine design projects, it became very clear that the freshman course sequence would have to change focus. Students would require explicit instruction in proper machining methods and the application of correct fit and tolerances in their designs. If these skills were explicitly taught in the freshman course sequence, they could then be fully utilized during the design and fabrication of the project in the machine design course. Another issue that became clear was that students needed specific instruction in CNC machining. This was not a skill that could be effectively taught by the shop technicians during a project build.

While the proposed changes were going through the approval process for the freshman course sequence, some changes were made to the machine design projects for the second iteration of the course. First, students were given some preliminary milestone dates they needed to meet during the build of their projects. The milestones included the completion of some of the basic functions of the students’ devices while there was still enough time left in the semester to make changes and complete a quality project build. The idea was to insure that the students had completed enough of the build to gain the understanding about machining and tolerancing early in the semester. That way they would be able to complete the build and create a well-functioning device by the end of the semester. The second change that was made to the machine design project build was the encouragement of using rapid prototyping technology. Students were encouraged to use the engineering program’s rapid prototyping machine to explore fit and function before spending a lot of time machining the finished version of complicated parts. They were also allowed to use the rapid prototyping machine to create finished components if the stresses in their design allowed it.

## 4.2 Freshman Course Sequence

After taking into account the lessons learned from the machine design projects, a plan was constructed for adapting the freshman course sequence to better fulfill the needs the students. The first semester of the sequence would continue to include the skills covered by the original sequence. It would include seven weeks of basic CAD introduction and a simple project using mostly woodworking tools. This course would continue to serve both mechanical and electrical engineering students and would focus heavily on communication and teamwork.

The second semester of the freshman course sequence would be modified to include only mechanical engineering students, and it would be used for developing machining skills and some advanced CAD skills. The CAD skills would include the creation of proper workshop drawings including correct dimensions and tolerances. The course would break the students into two groups. Half would be in the shop constructing two machining projects, while the other half would be in a classroom/computer lab setting working on the advanced CAD skills. The first course in the new course sequence was offered in the fall 2013 semester, and the second course will be offered for the first time during the spring 2014 semester.

The group of students in the shop will work under the supervision of shop technicians and will be given detailed instructions, complete with toleranced drawings, about how to create two simple projects. The class size will be limited to 24 students per section, so there will never be more than 12 students in the shop at one time with at least one shop technician present. Each project will require the students to perform some manual machining operations as well as some CNC machining operations using software to generate the G-code. Students will be allowed three weeks to complete each project.

The first machining project is a milling project consisting of two sliders connected by a rotating arm as shown in figure 1. The device serves no practical purpose, but it is a good exercise in making sure that the proper tolerances are held or the device will not move properly. The first step will be to construct the base and sliders using a manual mill. Step by step instructions will be given for creating the base. Students will then be required to apply the same skills to create the sliders with very little additional instruction. Next, detailed instructions will be given on how to use software to generate G-code and use a CNC mill to machine the arm. Since it is round and symmetric, the handle should really be done on a lathe. However, this is a milling project, so instructions are provided on how it can be created using a mill.

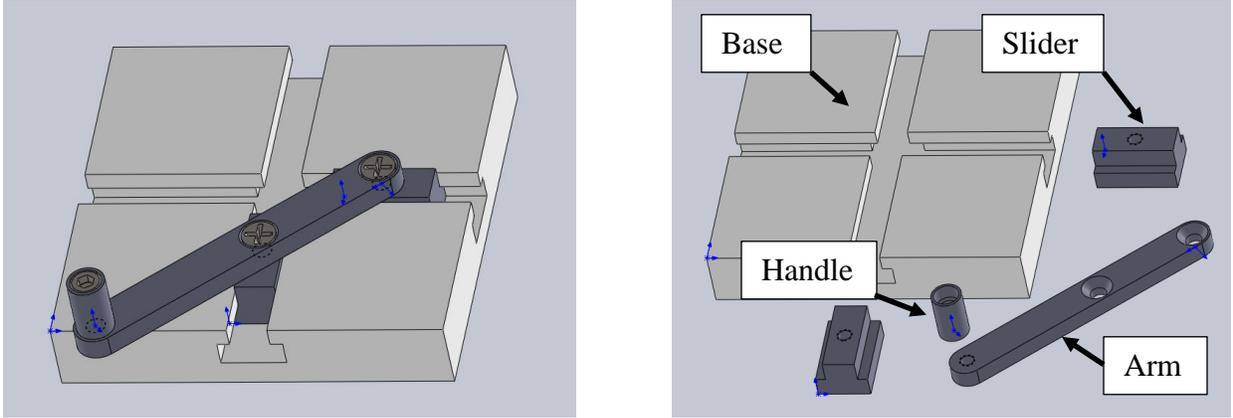


Figure 1: Slider Project

The second machining project is a lathe project where the students will create their own soft tipped hammer as shown in figure 2. Students will first be asked to create the hammer tips with detailed instructions using a manual lathe. Then, they will be given step-by-step instructions on how to use software to generate the G-code to machine the hammer head using a CNC lathe. Finally, they will be allowed to make any design they wish for the handle of the hammer on their own and machine it using either a CNC lathe or a manual lathe.

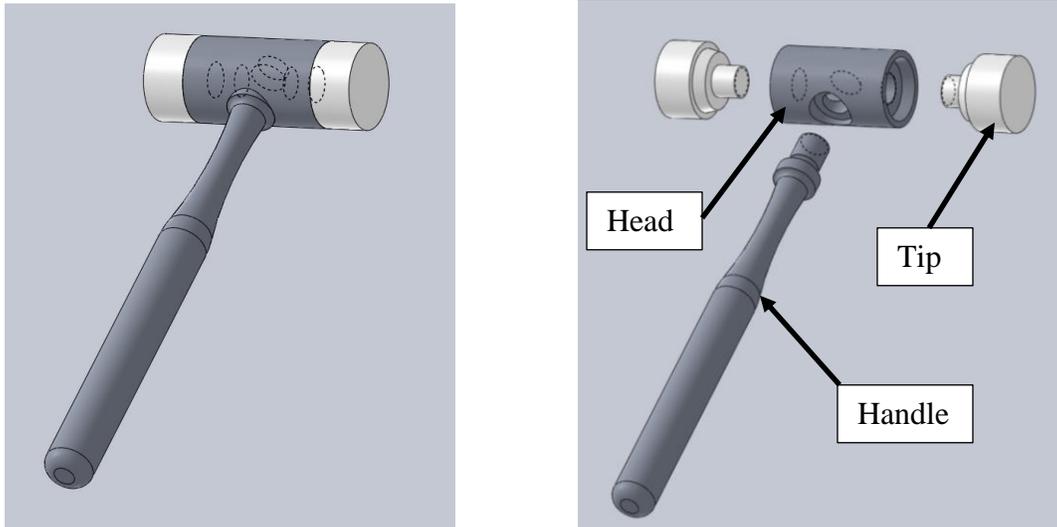


Figure 2: Hammer Project

While half of the students are spending six weeks in the shop completing the two machining projects, the other half will be in a classroom/computer lab setting working on some advanced CAD skills. The skills will concentrate on the creation of proper workshop drawings using proper tolerances, and will build on the basic skills were developed in the first course in the freshman sequence. The specific advanced CAD skills that will be covered are given below in table 1. After completing the six weeks of advanced CAD activities, the students will then switch with the students who have been working in the shop.

Week	CAD Skill
1	Projection and Isometrics
2	Dimensioning and Tolerancing
3	Drawing Views
4	Detail Drawings
5	Assembly Drawings with Bill of Materials
6	Geometric Dimensioning and Tolerancing

Table 1: Advanced CAD skills

In future iterations of this course, there is a plan to have the students complete a class project. The objective of the project would be to have small groups of students each develop a single part that will be assembled to become part of a larger device. The instructor would provide a basic picture of the device with materials chosen and general sizes of cross sections so that the students will only need to consider fit and tolerance issues. Each group of students would have to develop their individual component taking into consideration how it will fit with other group's components to complete the device. As this course matures, it may be also be adapted to include 3D printing techniques and welding. However, for the first time this course is taught, they will not be included.

Obviously there is not any assessment data available at this time for the new freshman course, as it has yet to be taught. However, there are plans to assess its effectiveness using student surveys and interviews as well as standard course evaluations. The long term effects of the changes made to this course will not truly be understood until the first group of students complete the machine design course. After this has occurred, alterations can be considered for this course, the machine design projects, and the senior capstone course.

### 4.3 Capstone Course

The last piece of the machining and tolerancing improvement implementation will occur in the capstone design course. The plan for the changes that need to be made in the capstone course will not be developed until the assessment data is available from students who have completed the other new courses. Consequently, the first class of students will have progressed through the new freshman course sequence and completed their machine design project before the final plan is developed.

While there is currently no plan for improving the capstone course, several observations from the course went into the development of the machine design projects and the development of the new freshman introductory course. First, many students have expressed apprehension about working in the shop during the capstone course. Even for very simple parts, the default action of capstone students seems to be "Can we find a machine shop to build this for us?" Second, students have demonstrated that they have problems with tolerance stack-ups and determining the correct tolerance for parts that are designed to fit together by two different teams. Capstone projects are typically done by several small groups of students working together to complete a larger project (often the formula SAE competition<sup>7</sup>). Tolerances are often not set properly, communicated clearly, and carefully machined which causes problems with the

project build. Also, students have demonstrated a lack of understanding between setting tolerances and manufacturing cost. Parts have been sent to machine shops for quotes with tighter tolerances than necessary causing the quotes to be unnecessarily high.

There will be many opportunities to assess student machining and tolerancing skills during the capstone course, once students have completed the new course sequence. Students are assessed both individually and as a group through formal oral presentations, poster presentations, written technical reports, and through weekly review of design notebooks. Design notebooks are collected from each individual student once a week and feedback is provided as to progress and quality of work complete. The notebooks are required to provide documentation of design work as well as fabrication. Each individual student is also required to prepare a written technical report documenting the final design and any relevant fabrication issues. After the first cohort of students has passed through the new course sequence, the capstone course will be assessed and an implementation plan developed to address any issues that arise with respect to machining and tolerancing.

## **5. Summary and Conclusion**

It was determined that it would improve the Mechanical Engineering Program at York College of Pennsylvania to include machining, drawing detailing, and tolerancing more explicitly in the curriculum. The inclusion of the new emphasis concentrated on three courses: a freshman introductory course, a junior level machine design course, and the senior capstone course.

The machine design course was the first to be enhanced with a semester long project requiring a prototype build. The project was very successful in helping students realize the importance of proper tolerances and the need for a basic understanding of machining skills. However, it was clear that more instruction was necessary for students to truly internalize these important concepts and realize how they could be used effectively in product design. Along with making some additions to the machine design project, it was determined that proper tolerancing and machining skills should be explicitly taught in the freshman introductory course sequence.

The freshman course sequence will be altered next semester to include two machining projects and instructional material including techniques for tolerancing and creating properly detailed drawings. The machining projects will include milling and lathe operations using both manual and CNC machines. Other instructional materials will include proper dimensioning, projections and detail drawings, and geometric dimensioning and tolerancing. The new course modifications will first be taught in the spring 2014 semester.

After the first cohort of students has passed through the new course sequence, assessment will be completed and a plan will be developed for the capstone course.

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