Creation and Integration of a New Manufacturing Lab into the Mechanical Engineering Curriculum

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Abstract:

Industrial employers seek mechanical engineering graduates with integrated knowledge and practical hands-on skills related to manufacturing. This paper focuses on the creation of a new manufacturing lab designed to strengthen the manufacturing preparation of engineering students to meet the needs of industry.

The new lab addressed the need for improvement identified by the ME Industrial Advisory Board. The Board is strongly influenced by small- and medium-sized manufacturers in northwest Pennsylvania. The board identified a need for improvement in the following areas: basic manufacturing/machining, drawing interpretation, metrology/measurements, statistical process control, process capability (based on six sigma concepts), and a basic understanding of manufacturing tolerances and CNC/automation. An emphasis was placed on teaching knowledge of the aforementioned items and not skills.

The continuous improvement initiative was also in response to students. The major complaint students had over the last several years was lack of experience in machining and basic manufacturing which prevented them from completing senior design projects and hindered industry collaboration. Their complaint directly related to ABET Student Outcomes (c) and (k). The creation of the new lab and associated new equipment addresses a critical need identified by the Advisory Board and students for continuous improvement of the ME program.

1. Introduction

A question that often arises when discussing mechanical engineering curriculum is “can a student become a successful engineer without ever walking into a machine shop or possessing practical, hands-on manufacturing skills?”[1] Often times the answer is ‘yes’, especially if a student is going on to graduate school or pursuing a career in R&D, technical sales, etc. In these cases, a general understanding of “how it’s made” may be good enough. This knowledge can be easily obtained in an undergraduate material science course[2]. Industrial employers, however, are increasingly seeking mechanical engineering graduates with integrated knowledge and practical hands-on skills related to manufacturing, particularly in design and manufacturing positions where a company’s success is greatly impacted by how well mechanical components are designed. This includes communicating designs effectively through working drawings that are properly dimensioned and toleranced and can be manufactured cost-effectively.

This paper focuses on the creation of a new manufacturing lab integrated into the mechanical engineering curriculum at Gannon University. This continuous improvement initiative was in response to suggestions made by multiple sources including the Industrial Advisory Board, alumni and students. The new lab (designated ME 330) was designed to strengthen the manufacturing preparation of engineering students to meet the needs of the industry. Over the course of the past few years, the lab has been significantly upgraded to include new engine lathes, knee mills, CNC equipment, various 3D printers, laser scanners and fabrication equipment (figure 1). Implementation of the new equipment has allowed for the creation of several new lab modules. Each module has been uniquely designed to address the needs identified by the advisory board, students, and alumni.

Figure 1: The new manufacturing lab at Gannon University showing some of the new equipment.

This paper provides a historical background detailing the motivation behind the creation of the new manufacturing lab. This is followed by a brief overview of each lab module with emphasis on how they meet the critical needs. The paper concludes with a summary of student feedback surveys and plans for future improvement.

2. Background

Prior to implementation of ME 330, most of a student's exposure to manufacturing came from a junior level manufacturing processes course[3]. This 3-credit course covers such topics as: turning, milling, tool materials, grinding, powder metallurgy, polymer processing and molding (thermosets and thermoplastics), castings, abrasive machining, drilling, broaching, sawing, metal forming, forging, and welding[4]. Other topics include machining calculations for speed, feed, depth of cut, required machine power, cutting forces, tolerances, GD&T and economic justification. All of these topics are designed collectively to meet the course objective:

> "Familiarize students with the manufacturing methods and processes, equipment and economical aspects for the manufacturing of various materials into useful components to meet the objectives of a mechanical designer."

The course ensures this objective is met but does little in the way of providing students with any "hands-on" manufacturing experience.

2.1Feedback from the Industrial Advisory Board and Alumni

The new ME 330 lab addressed the need for improvement identified by several sources. Feedback for the ME program at Gannon is collected continuously from industry and alumni. As part of the ABET assessment plan, a survey is sent out to alumni several years after graduation. Many of these alumni also serve on the ME Industrial Advisory Board. The ME Industrial Advisory Board meets at least once per semester in a formal setting where they are asked to review the ME curriculum and make suggestions for improvements. The Board is strongly influenced by small and medium-sized manufacturers in northwest Pennsylvania in traditional industries such as machining, fabrication, plastic injection molding, foundries and powder metal.

Throughout these interactions with industry and alumni, areas of improvement mentioned most frequently included a better understanding of: machining and manufacturing, dimensioning and tolerancing, drawing interpretation, metrology/measurements, statistical process control, process capability (based on six sigma concepts), and a basic understanding of CNC and automation.

2.2 Feedback from Students

This continuous improvement initiative was also in response to students. Mechanical engineering students at Gannon University are required to complete a two-semester senior design "capstone" project[3]. These are typically industry-sponsored projects where students work in groups. The senior design projects almost always require the fabrication of full-scale working prototypes or special test fixtures. These "real world" projects exposed a weakness in the curriculum. Although students had very good analytical skills, they did not possess the "hands-on" skills required to complete their project builds. The exit survey for the senior design course showed the major complaint students had was lack of experience in machining and basic manufacturing which prevented them from completing their senior design project builds and hindered industry collaboration. Other common complaints included the need to incorporate more CAD into the curriculum on an on-going basis (besides just the freshman graphics course) and lack of access to 3D-FDM printers for rapid prototyping. Their complaints directly related to ABET Student Outcomes (c) and (k) and were addressed in the new manufacturing lab.

2.3 Feedback from the Northwest Industrial Resource Center (NWIRC)

The NWIRC is a non-profit organization providing manufacturing services to 13 counties in northwest and north central Pennsylvania[5]. There are approximately 1,550 small (<500 employees) manufacturing companies in this geographical region. These companies hire Gannon engineering students. A Gannon engineering faculty representative is often a member of the board[6] and therefore interacts quarterly with some of these companies and other board members. Common complaints were engineering graduates with the inability to properly detail and interpret engineering drawings and lack of practical "hands on" experience.

3. Benchmarking

Other schools have recognized the benefit of offering practical "hands-on" machining skills. Literature search and curriculum reviews have shown some schools such as Purdue, San Jose State, Michigan Tech, the University of Alabama, and the University of North Carolina have a machining course in their curriculum[1]. The University of Michigan offers ME 250 Introduction to Design and Manufacturing[7]. ME 250 is structured as a lecture and laboratory course. The course provides students with a "hands-on" experience in design and manufacturing. The course was similarly added to support the senior capstone project based on recommendations from a review committee. At Bingham Young University a senior design capstone course titled Integrated Product and Process Design was added to both the Mechanical and Manufacturing Engineering curriculum[8]. Teams of 4 to 5 students in both manufacturing and mechanical engineering work on industry sponsored projects that involve both design and functional prototypes. Representative students from both departments ensure cross-training occurs and the importance of integrating design and manufacturing is realized.

4. Implementation of the New Manufacturing Lab, ME 330

ME 330 was added to the curriculum in fall 2009 as a 3-hr/week, 1-credit lab. As new equipment was added to the lab, new lab modules were created. Currently there are eight lab modules (3-hr each) and four lectures (3-hr each). At the beginning of each semester, all ME 330 students are required to take an OSHA mandated 3-hr safety course on the use of machine tools and safe manufacturing practices. After completion of the safety course, students must take and pass a safety exam before their names are maintained in a database for the duration of their stay in the department. This gives them access to the lab for senior design projects as well.

All lectures are given by a faculty member. Labs, however, are administered by both a faculty member and technician (machinist) since multiple labs occur simultaneously. The four 3-hr lectures, designed to prepare students for the lab modules, are:

a) Intro to metrology and geometric dimensioning and tolerancing (GD &T). The key here is to emphasize how to interpret dimensions given on working drawings so components can be manufactured and inspected properly. Sample components are inspected and a full dimensional lay-out is completed in class. Recommended tolerances for traditional manufacturing processes such as machining, drilling, grinding, etc. are discussed.
b) Basics of milling and turning. A review of speeds and feed calculations as well as lathe and mill operations. Note, the lecture is followed by a 1-hr demo on lathe and mill.
c) Statistical process control and process capability evaluated on the basis of Six Sigma concepts. This includes a summary of constructing histograms, calculating mean, standard deviation, normalcy of data, coefficient of skewness and various process parameters (C_p, C_r, C_{pk}). Accuracy versus precision and process capability based on C_{pk} are discussed. Relationship between tolerance and machine capability is also discussed.
d) CAD and CAM review (using Pro/ENGINEER Creo). Basic G-code programming followed by a demo on the HAAS simulator.

Again, the purpose of these lectures is to prepare students for the lab modules. The lab modules are designed to meet the objectives defined in section 2.1, 2.2 and 2.3. An overview of each lab module follows.

4.1 Lab 1: Process Capability for Lathe Turning Operation

Main Objective: The main objective of this lab is to introduce students to the concept of process capability based on the Six Sigma concepts. Various statistics are used to determine accuracy, precision, and process capability for a lathe turning operation.

No two parts coming from any manufacturing process are exactly the same – variability is observed in the output. Each process has a certain inherent variability. The controlled reduction of output variability is the primary objective of quality engineering. In this lab, groups are given thirty-four brass specimens initially at 11 mm in diameter (figure 2.a.). Students are required to turn the OD of the specimens down to 10 mm +/- 0.4 mm (figure 2.b.). The goal is to optimize the turning process to minimize variability. Four specimens are used as set-up pieces to dial in the process (i.e. determine optimal speed, feed, tooling, etc.). Once the process is dialed in, thirty samples are machined in series without changing any lathe parameters. The OD's of all thirty specimens are measured and recorded. Results are presented in a formal lab report (figure 2.c.). At the end of the semester, all group results are presented and displayed. Population statistics for the entire class are then calculated and followed up by discussion.

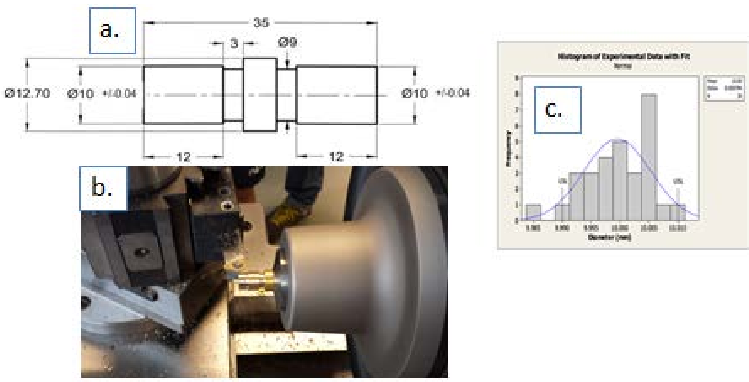

Figure 2: Lab 1, Process Capability, a) specimen geometry, b) specimen turning on lathe, c) sample student output from report.

4.2 Lab 2: Process Capability Study for Surface Finish in Machining

Main Objective: The main objective of this lab is to introduce students to the concept of surface finish and to analyze the idealized effect of the feed, speed, depth of cut, tool nose radius and material type on the resultant average roughness, Ra.

Students are given several specimens with geometry shown in figure 3.a. The OD of each sample is machined via turning on a lathe. The specimen has 3-humps and surface finish measurements are taken at ten equally spaced locations along the circumference of each hump for a total of thirty measurements per specimen. The average roughness, Ra, is measured using a Mahr Pocket Surf ™ profilometer (figure 3.b.) The impact of various lathe operating parameters such as feed rate (figure 3.c.) is investigated. Various statistics are implored to analyze the process and to predict the location of the average roughness population mean for various machining parameters with a reasonable degree of confidence (90% confidence). Finally, analytical equations are used to calculate surface roughness. Analytical and experimental values are compared. A formal lab report is required.

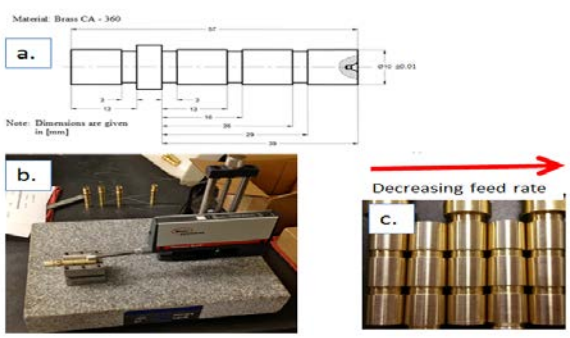

Figure 3: Lab 2, Process Capability Study for Surface Finish, a) specimen geometry, b) measuring average roughness, Ra, c) specimens machined at varying feed rate.

4.3 Lab 3: Fundamentals of Lathe Operations and Lab 6: Basics of Milling

Main Objective: The main objective of these two labs is to give students practical "hands-on" machining experience using a manual lather (Lab 3) and manual mill (Lab 6) with metrology.

Prior to the respective lab, students are required to print out and review the drawings and create solid CAD model (using Pro/E CREO®) and email these models to instructor. Multiple machining operations are required to make each part. For example, the lathe part (Figure 4.a. requires twelve machining steps (facing, turning, grooving, threading, drilling, knurling) to complete. The milling part (figure 4.b.) also requires twelve operations. In addition to the CAD models, students are required to turn in parts which must meet drawing tolerances, a marked up drawing with full dimensional lay-out and process plan detailing all the steps, feed, speeds, etc.

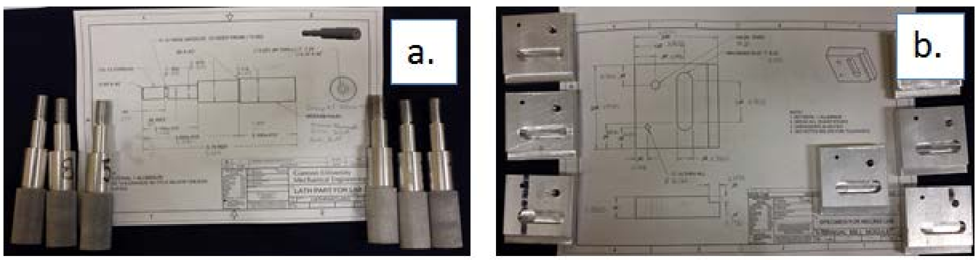

Figure 4: Lab 3 and 6, Fundamentals of Machining, a) lathe part, b) mill part. Students are required to machine both parts to spec.

4.4 Lab 5: 3D Printing (Rapid Prototyping)

Main Objective: The main objective of this lab is to introduce students to fusion deposition modeling (FDM) using various 3D Printers for rapid prototyping of mechanical parts.

Prior to lab, students are required to produce solid CAD models (using Pro/E Creo®) of two components: a link and a drill bit end cap (figure 5.a.). In the case of the link, a drawing is provided and students create the CAD model as well as their own drawing to turn in. For the drill bit end cap, students are given actual parts several weeks before class and perform a dimensional lay-out (or use the laser scanner) to reverse engineer the part. A solid CAD model and detailed drawing of the end cap is then created. Students bring STL (stereo-lithography) files of both parts to class and use a FDM printer (such as the one shown in figure 5.b.) to print parts out of ABS. Parts are then inspected and a full dimensional lay-out is completed. Students turn in their parts with marked up drawings showing dimensional lay-out. Note, in addition to rapid prototyping, this lab also provides students with an extensive review of CAD.

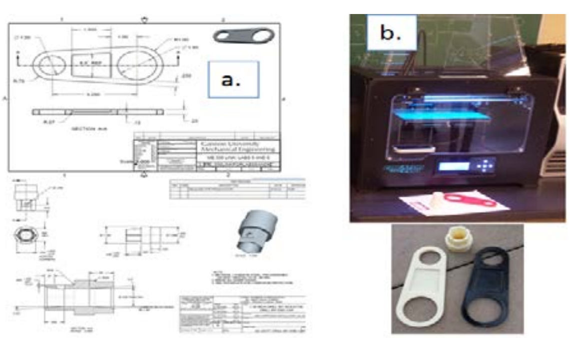

Figure 5: Lab 5, 3D Printing, a) link and drill bit end cap, b) one of the FDM printers used for rapid prototyping with samples shown.

4.5 Lab 4: Reverse Engineering a Part using a Laser Scanner

Main Objective: The main objective of this lab is to introduce students to reverse engineering using a Picza® laser scanner.

Students are given several mechanical components to reverse engineer using the laser scanner. Optimal scanner parameters are determined (usually by trial and error) to get the best scans. Geometry from the scanner is then imported in to a CAD package where surfaces are "fixed" and dimensions are measured in CAD. CAD dimensions are compared to actual measured dimensions to determine accuracy of scans. A formal lab report is required.

4.6 Labs 7 and 8: Intro to CNC Machining

Main Objective: The main objective of this lab is to introduce students to CNC machining which includes G-code and CAM.

In this two-lab sequence, students write G-code and machine the block shown in 4.b. on a HAAS vertical machining center. Prior to machining, the G-code is evaluated on a simulator and checked for errors. Students observe the time difference between machining the part manually versus the CNC mill (3 hr vs. 10 minutes). Students also program a Roland table top router to machine the link shown in figure 5 out of a block of wood. The sequence concludes with an overview of CAM which allows for the machining of a complex bottle opener.

5. Student Feedback and Assesment

A survey was prepared and administered to the students at both the beginning and end of the semester. The purpose of the survey was to determine if the objectives defined in section 2 were met. The survey contained the following 9 questions:

As a result of taking ME 330, my knowledge in the following areas has improved:

1. Ability to perform basic turning operations using a lathe.
2. Ability to perform basic milling operations using a mill.
3. The importance of manufacturing tolerances and difficulty holding tight tolerance.
4. Ability to use measuring devices (metrology) to inspect parts and create dimensional lay-outs.
5. Working knowledge of statistics related to process control and process capability based on six-sigma principles.
6. Ability to use 3D printers.
7. Ability to use laser scanners in conjunction with CAD to reverse engineer parts.
8. A basic understanding of how CNC machine tools can improve a manufacturing process.
9. Having to perform various CAD operations throughout the course using Pro/Engineer Creo was helpful in maintaining my CAD skills.

Results of the survey are shown in Figure 6. The values shown are mean values from 32 student responses (i.e. two labs with 16 students). The results clearly indicate that while the experience level of students at the start of the semester was low, the objectives were met after completion of the course.

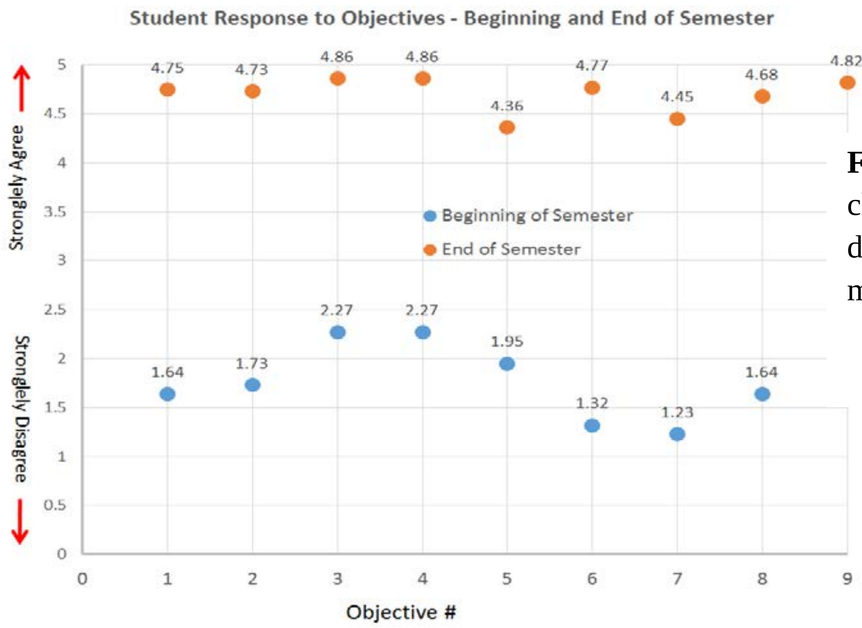

Figure 6: Survey results clearly show objectives defined in section 2 were met.

6. Conclusion and Future Improvements

The new ME 330 manufacturing lab implemented fall 2009 and revised each year since, has proven effective in meeting all the objectives defined in Section 2. Namely, the lab provides students with a "hand-on" practical machining experience, statistical process control, metrology, dimensioning, tolerancing, interpreting and creating working drawings.

Future plans for improvement include adding two additional machining modules and a welding module. Three more labs can be added if the 3D printers and laser scanner are moved to another room. This will allow four groups (instead of three) to work simultaneously in the manufacturing lab and hence, three more lab modules can be added to the course schedule.

The addition of two more machining labs allows for a more sophisticated project build. For example, the truck belt tensioner shown in figure 6 contains both milled and turned components which must fit together so the assembly functions properly. This could even be a multi-year capstone-type project where the geometry is modeled in freshman engineering graphics, components are analyzed and designed in a junior level machine design course and finally, the system is machined and built in the senior level manufacturing lab.

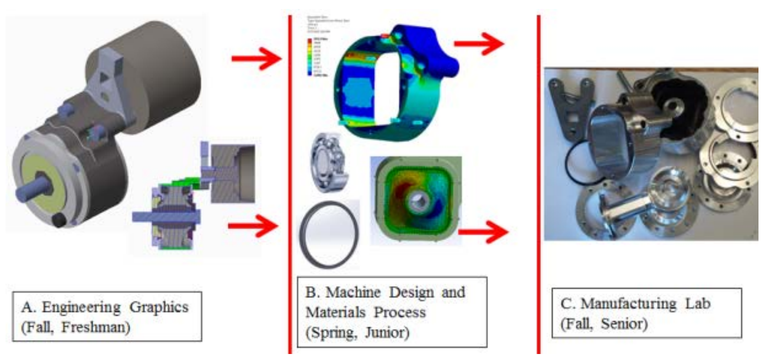

Figure 6: Addition of two more machining labs allows for a more sophisticated project such as the belt tensioner which could be a multi-year project.

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Robert J. Michael, Ph.D., P.E., Assistant Professor in the Mechanical Department at Gannon University, obtained his B.S.M.E. degree from Akron University where he graduated summa cum laude, and his M.S. and Ph.D. degrees in mechanical and aerospace engineering from Case Western Reserve University. He joined the faculty at Gannon University in the Fall of 2013 as an assistant professor in the Mechanical Engineering department. Prior to his employment at Gannon, Dr. Michael spent several years in industry where he worked as an industrial product designer and aerospace product designer for LORD Corporation and as general manager for National Tool and Equipment. • Courses taught include finite element analysis, material science, statics, strength of materials, materials lab, machine design, product design, production design, plastic design and FE analysis, manufacturing and engineering graphics. • Research interests include design and optimization of elastomer components, elastomeric fatigue properties, hyperelastic modeling of elastomers, failure analysis of elastomeric components, seismic analysis of storage racks, experimental testing and characterization of materials and general machine design. • Dr. Michael holds several patents and has several patents pending primarily in the area of noise, vibration and harshness (NVH) type isolation products. He has published extensively in this area as well. He is a licensed professional engineer in the Commonwealth of Pennsylvania.

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