Manufacturing Practices – A Hands-On Course in Metalworking for Engineering Undergraduates

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Abstract – It is a recurring observation among industry stakeholders that graduating engineers are well-versed in engineering sciences, but lack certain fundamental skills needed to make immediate contributions in the workplace: ability to function in teams, aptitude for creative synthesis and design, communication skills, and an understanding of the realities of manufacturing. At Mercer University, a course in Manufacturing Practices provides students with the opportunity to gain significant hands-on fabrication experience in a machine shop environment while developing teaming, design, and communication skills. The course has proven valuable in preparing students for the senior-year capstone design experience as well as for the realities of the workplace.

Keywords: Manufacturing practice; machine shop; welding; teaming.

INTRODUCTION

Employers of engineering graduates inevitably have certain expectations of their new employees. It will always be a struggle for engineering schools to deliver graduates that meet all of these expectations. In particular, as technology advances, the demands on the graduate, and therefore on the colleges, increase. Breadth versus depth and fundamentals versus applications are constant sources of debate among those charged with establishing and refining engineering curricula. It is clearly not possible to be all things to all employers.

A common thread among engineering employers is that graduates lack fundamental skills needed to make immediate contributions: understanding realities of manufacturing practices, ability to function in teams, aptitude for creative synthesis and design, and communication skills. The following observations are typical over a wide range of firms employing engineers. The head of a small computer systems engineering company wrote [Galvan, 1]:

> We expect recent college graduates to arrive at the work place fully armed and ready to contribute to the bottom line. . . . Additionally, it appears that recent college graduates generally lack practical, immediate skills; skills demanded by current market forces; skills such as being able to work in teams, being familiar with current technologies, and a fundamental understanding of systems engineering are glaring examples. . . . The currency of detailed technical skills is important, but graduates also lack fundamental skills. Skills with the written and spoken language are deteriorating. In fact, it has become a cliché that scientists and engineers can not write.

A representative of a large domestic aerospace contractor made the following observation [McMasters, 2]:

> We see too many new graduates with an inadequate grasp of what engineering (as contrasted with engineering science) is and how one practices it, particularly in the currently evolving industry environment. Too few of our engineering graduates seem to have any idea of how to work in teams or how to manufacture anything.

The reasons for this situation are many and complex, as are the potential approaches to addressing it. At Mercer University, a course in Manufacturing Practices, required of students specializing in Mechanical Engineering, Industrial Engineering, and Engineering Management and typically taken in the junior year, provides students with

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an opportunity to gain significant hands-on fabrication experience, while developing teaming, design, and communication skills. This course, in combination with a freshman design course and the senior capstone design experience, gives students valuable experience in putting into practice knowledge gained in more traditional lecture and laboratory courses while bringing to bear certain critical aspects of life on the outside.

COURSE OVERVIEW

A major focus of the course is to provide each student with a hands-on familiarity with machines and tools used in typical fabrication processes. At the first class meeting, each student is assigned to a team of two to three members. The members of each team work together on all group activities during the term. Course activities consist of three major parts, each comprising approximately one-third of the semester:

- Machine shop familiarization
- Welding technique familiarization
- Design project

The class meets twice a week for three hours each meeting. A typical class session begins with a presentation by the instructor, explaining the objectives for the class and demonstrating the tools and equipment being used. The demonstration is generally followed by an exercise in which each team takes a turn on the machines to accomplish a specific task, such as drilling a specified hole pattern, or cutting and bending sheet metal to specifications. Each member of the team is required to take a turn on the machines to ensure that all students have a nearly equal hands-on experience.

Grades in the course are based on the following:

- Take-home quizzes covering material from the assigned reading in the texts and in-class presentations
- In-class written tests at the end of the machine shop and welding modules
- Practical exams at the end of each block of instruction in shop skills. Each student makes an article to specifications using machines and techniques learned during the exercises
- The design project, in which each team designs and builds a fixture for the production, on a vertical milling machine, of a specified part. During the course of the project, each team produces a preliminary design report, a final design report, and fabricates and demonstrates the fixture.
- Performance, which is a subjective measure of the students' attitude, attentiveness, safety consciousness, and team contributions.

COURSE COVERAGE

Students gain exposure to a variety of machine tools, hand tools, and welding equipment during the first eight to nine weeks of the semester divided between the machine shop and the welding shop. Safety procedures and equipment are covered in detail during the first class meeting and re-emphasized throughout the term. A particular point is made that students are responsible not only for their own safety but for the safety of their classmates as well. Students are encouraged to ask questions whenever they are unsure about a procedure or if they feel uncomfortable about a process. Most importantly, no pressure is put on the students to finish a particular exercise before the end of the scheduled class meeting.

Machine Shop Module

During the machine shop module, students gain familiarity with capabilities, operations, and processes involving a number of typical machine shop tools and machines, Figure 1. Exercises and presentations include:

- Measurement using rules, micrometers, and vernier calipers

- Threads, thread classes, fits, tapping and drilling
- Dimensioning, tolerancing, and manufacturing drawings
- Drilling with a drill press, grinding, sawing with a band saw, and use of hand tools
- Use of a lathe for turning, cutting threads, and knurling
- Precision milling using a vertical milling machine
- Sheet metal cutting with a shear brake, riveting

Figure 1. Students work at a lathe, milling machine, and press brake

For the practical exams, each student makes a meat tenderizer and a chimney cap (Figure 2). The meat tenderizer uses lathe techniques including turning, tapering, knurling, and cutting threads, as well as milling operations to cut the pattern on the head. The chimney cap involves layout, use of the press brake for cutting and bending, and riveting. Teams work together on the practical exams, but each student must produce a finished article.

Figure 2. Machine shop practical exam: meat tenderizer; chimney caps

Welding Techniques Module

During the welding module, students gain exposure to:

- Oxyfuel gas welding
- Shielded metal arc welding (SMAW)
- Gas metal arc welding (GMAW)
- Resistance welding,
- Plastic welding
- Soldering

For the practical exam, each student makes a boot scraper (Figure 3).

Figure 3. Welding shop practical exam: boot scraper

DESIGN PROJECT

The design project comprises a major component of the course, bringing into play machine shop techniques, working in teams, written and oral communication, and design. During the fourth week, the teams are given a Request for Proposals (RFP) containing the specifications for a fixture for mass-producing a specific part from blanks on a vertical milling machine. Each team is given three weeks to respond to the RFP with a preliminary design report, followed by a detailed design report four weeks later. The teams spend the last four weeks of the term building their fixture from the detail design, and demonstrate it during the last class period.

Fixture requirements from a typical RFP are shown in Figure 4. The part that the fixture is designed to produce is shown in Figure 5. Each team submits a written proposal which amounts to a preliminary design in response to the RFP. As with industry RFPs, proposals must adhere to specified requirements which are detailed at a brief "bidder's conference." The proposal is required to include three parts:

- Problem Definition, in which the team communicates its understanding of the problem and the requirements
- Design Concept Description, which contains an overview (with drawings) of the fixture configuration and a description of how the design will meet each of the customer requirements.

- Analysis of the Design Concept, which demonstrates that the blank is accurately and securely held in the fixture during all machining operations.

Problem: Design and build a fixture for mass producing a Lovejoy coupling (see Figure 5) from blanks using a vertical milling machine. The fixture must provide for safe, rapid accurate machining of blanks into the required part.

Detailed Requirements:

- The fixture shall provide adequate support for machining parts without using a vise.
- Proper alignment of the blanks shall be accomplished without the aid of a sine plate.
- The head of the milling machine shall remain vertical for all machining steps.
- The fixture shall be capable of making the parts from blank rounds nominally 2 in diameter x 1.5 in. The lateral edge of the blanks will be either saw cut or rough milled.
- Once each blank is clamped in the fixture, proper machining shall not require any measurement of the blank itself. All finish dimensions shall be obtained by movement of the milling machine table relative to a positive reference point in the fixture itself.
- The machine operator shall be capable of finding that positive reference point accurately and reproducibly if necessary. This shall be possible without the use of an edge finder.
- The fixture shall provide enough clamping points to prevent excessive movement of the blank while it is being machined.
- The fixture shall provide for accurate, reproducible alignment of the fixture with the long axis of the table of the milling machine.
- Two holes shall be provided for securely and accurately mounting the fixture to the table of the milling machine.

Figure 4. Typical specifications for the design project.

Figure 5. Lovejoy coupling

Teams then receive feedback from their proposals and are given detailed requirements for the Final Report. The Final Report contains all the information required to fabricate and assemble the fixture and to use it to make the part. As such, it contains the following elements:

- A Bill of Materials, including estimated costs, for the raw materials comprising the fixture.

- Detail drawings of each part comprising the fixture, containing sufficient information for a machinist to fabricate the part
- A parts list
- An assembly drawing, showing how the fixture is put together from its component parts
- Detailed, step-by-step instructions for using the fixture to make the part, including:
  - Mounting, securing and aligning the fixture on the milling machine
  - Mounting, securing, and aligning the blank in the fixture
  - Setting the zero position
  - Proper cutting tools to be used for each machining operation
  - Tool paths for each machining operation

A key focus of the Final Report is its clarity and completeness. It is emphasized that this report constitutes the sole enduring documentation for the fixture. It must be sufficiently self-contained that, in twenty years, someone could use it to build and operate the fixture. The ability of engineers in industry to provide clear, complete, and self-contained documentation of their designs is in many respects just as valuable as their ability to design.

The teams spend the last five weeks of the term building and testing their fixture according to the final design (Figure 6). The last class period, each team demonstrates their completed fixture (Figure 7) to the class, discussing its features, any design changes made during the process, and lessons learned during its design and construction.

Figure 6. Student teams work on their fixtures

Figure 7. A completed fixture with the fabricated part

COURSE OUTCOMES AND STUDENT REACTION

It is not the intention of the course to enable students to become certified machinists. Rather, the focus is to give them a basic familiarity with machine shop and welding shop tools, practices, and capabilities. This is accomplished in large part via the hands-on nature of the class activities. Students gain a firm appreciation of what it takes to make a part to specifications, as well as the effect of dimensioning and tolerancing on fit, form, and function. It is important that design engineers be able to communicate effectively with manufacturing engineers and technicians, and the experiences gained in this course are valuable in developing this capability.

Pre-requisites for the course include Statics and Graphics and Visualization. Students use their knowledge of statics in their fixture design to ensure that the blank is adequately restrained during machining operations. They apply their graphics education to produce detail and assembly drawings in the final design report. Thus, this course is perhaps their first opportunity to apply what they have learned in previous courses to a concrete outcome.

This is also perhaps the first course in which students function as a member of a team from the very beginning. Because of the nature of the class activities, class attendance and punctuality are mandatory. It is impressed on the students from Day One that their individual success and the success of their team are closely linked. With very few exceptions, students have shouldered their team responsibilities very well; due to the small class size and small team size, it is difficult for a non-functioning team member to hide.

In general, the atmosphere in the shop is intentionally low-key and non-threatening. For many students, the shop is a relatively unfamiliar environment, and some are clearly intimidated by the activities. Each student is required to take a turn on the machines; it is gratifying to see their confidence increase as the term progresses. Discussions of safety considerations accompany each new machine tool being used. For safety reasons, students are encouraged to work deliberately and to ask questions; the policy is not to rush the students to complete a project. Horseplay is absolutely not tolerated in the shop, and has rarely been an issue.

Standards for both the preliminary design proposal and the final report are enforced fairly rigidly. The requirements for reports of this nature in an industrial context are emphasized, as are the reasons behind strict formatting and content requirements. In many industries, a design can long outlive its designers; when modifications are required, the documentation provides the only link to the original design intent and specifications. Hence, a prime course objective is to give students an appreciation for the importance of clear and standardized documentation.

Class enrollment is limited to twelve students per section. Two sections are typically run each semester. This class size enables four teams of three students each. Because Mercer's machine shop has four vertical milling machines and four lathes, the teams can work in parallel. Class demonstrations are typically performed on one of the machines, with students gathered around to watch; having more than twelve students in the group would severely limit visibility and effectiveness of the demonstrations.

An engineering technician and a faculty member administer the course. The technician is fully versed in machine shop operations, and requires (and exhibits) nearly infinite patience in explaining and demonstrating the necessary skills. The faculty member is responsible for the preliminary and final design reports and for providing back-up to ensure that operations run smoothly in the shop. Clearly, a key to making the course work effectively is to have on staff a technician with the necessary machine shop skills as well as the necessary temperament.

Student reaction to the course tends to be very positive. Undoubtedly, this is partly due to the fact that it is a welcome change of pace from the traditional lecture and lab courses that dominate the curriculum. But there is also a sense of accomplishment from learning new skills and having something tangible to show for it at the end. "I enjoyed actually making things," is typical of the student responses to the course evaluation. They also have a genuine appreciation for the effort put forth by the course instructor. "Mr. Campbell deserves some major recognition in being an amazing instructor in the lab. He is very calm and understanding when a student has questions or cannot physically perform assigned tasks."

SUMMARY AND CONCLUSIONS

A course in Manufacturing Practices at Mercer University's School of Engineering provides students with a hands-on experience in the machine shop and the welding shop. Students perform exercises on a variety of machine tools – drill press, band saw, grinder, lathe, milling machine – as well as welding equipment to gain confidence, if not proficiency, in using the equipment. Practical exams give the students the opportunity to apply their new-found skills to the fabrication of potentially useful items.

A major component of the course is a project, in which student teams design, build, and demonstrate a fixture to be used in the machine shop to fabricate a specified small part. Teams respond to a Request for Proposals with a preliminary design, followed by a detail design documenting fixture fabrication and use. The teams then build their fixture in the machine shop and demonstrate them to the class at the end of the course.

In addition to the experience of fabricating items to specifications, course activities provide students with the opportunity to develop teaming, design, and communication skills. The course therefore serves as a useful bridge between the freshman design course and the senior capstone design experience. Furthermore, it at least partially addresses industry needs for young engineers having the requisite skills to contribute in the modern industrial environment.

References

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