Improving the Relevance of Manufacturing in a Mechanical Engineering Curriculum

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Abstract

In the 2000-01 academic year, Michigan Tech University implemented a new mechanical engineering curriculum (coincident with a change from quarters to semesters). To improve the relevance of manufacturing in that curriculum, faculty and staff developed a new sophomore level course Integrated Design and Manufacturing. The course is part of a design and manufacturing thread that begins in the freshman year and extends to the senior year. The course presents an overview of the product development process, discusses the major unit manufacturing processes along with part design implications, and introduces manufacturing systems. The course departs from the earlier quarter long manufacturing course by emphasizing practice more and theory less. A new laboratory provides hands-on manufacturing experience to all students.

Introduction

The Mechanical Engineering—Engineering Mechanics Department at Michigan Tech has for many years placed a high value on manufacturing in its curricula and research. A change from quarters to semester in the 2000-01 academic year prompted faculty and staff to review the entire undergraduate mechanical engineering curriculum and make revisions. The primary goals of the new curriculum are making the first year common to all engineering majors, integrating design and manufacturing concepts from the freshman through senior years, and increasing the hands-on component with new lab classes and facilities. An important part of the overall curriculum revision was to improve the manufacturing component, particularly in the context of improving design capabilities.

In the quarter system, all mechanical engineering (ME) students were required to take a 4 credit class *Introduction to Manufacturing Processes*. This was a junior level class (often postponed until the senior year) consisting of 3 lectures and 1 lab session per week. The course focused heavily on quantitative analysis of manufacturing processes. For example, expressions for forging and extrusion forces were derived. Machining forces and chip formation geometry were presented in detail. The weekly lab reflected the overall philosophy of the course: quantities (such as forces) were measured during various manufacturing processes (extrusion, powder metallurgy, turning, etc.) and compared to theoretical predictions. During the lab sessions, only a few students actually operated manufacturing equipment; most students watched and recorded data. The class provided a good basis for the senior elective courses on metal forming, casting, machining, and plastics. The course did not, however, create a passion for manufacturing in most students. It did not adequately convey the capabilities and limitations of various manufacturing processes. Such knowledge is critical for good design. The curriculum revision gave us a chance to make some improvements.

Key Elements of New Course

In the new course we adopt a slightly different philosophy. We believe the best way to generate enthusiasm for manufacturing is to do manufacturing. This would mean improving the lab to make it more hands-on. It would also mean shifting the focus from the theory to the practical aspects of manufacturing. In addition, we wanted to expose students to manufacturing early (during sophomore year). The new curriculum exposes our students to design from the freshman through senior years with a heavy dose (two mechanism design classes) in the junior year. We felt it important that students experience manufacturing early so that they naturally consider manufacturing issues while doing design. In addition, we hoped the early exposure to manufacturing would motivate the learning of theoretical topics in later engineering science and manufacturing elective courses.

In developing the new 4 credit course *Integrated Design and Manufacturing*, we borrowed heavily from others. A number of schools introduce hands-on manufacturing experiences to their ME students in the freshman[1] or sophomore years[2-5] with good results. One of the benefits has been improved performance in the senior capstone design course[2]. A number of schools integrate design and manufacturing concepts in an introductory course[2,6]. While some of these focus primarily on design and introduce a couple manufacturing processes to give students the experience of making a prototype, our course emphasizes manufacturing more than design. It presents all the major manufacturing processes along with considerations for design. It also presents the product development process and the role of design and manufacturing in it.

The new course has five primary learning objectives. At the end of the course, students will be able to:

- Identify the stages of a typical product development process
- Identify manufacturing processes and equipment
- Calculate quantities such as force and power for various manufacturing processes
- Identify design features that impact manufacturability
- Select a suitable process or sequence of processes for manufacturing a part

The course begins with a 2-3 week overview of the product development process. Topics such as identifying customer requirements, defining product specifications, generating concepts, and selecting concepts are emphasized. The next ten weeks are devoted to manufacturing processes including metal forming, casting, machining, and plastics processing. We discuss process capabilities, such as the allowable part geometries and work materials, achievable dimensional accuracies and surface finish, effect on material strength, tooling and machinery costs, and production rate. By the end of the course, students view each new process through this same filter. They ask what part strength and accuracy can be achieved. And at what cost and speed. They are able to compare the capabilities of competing processes such as casting, forging, and machining. They understand how small changes in design geometry or surface finish specification can significantly improve manufacturability and reduce cost. The last 2-3 weeks of the semester address issues of mass production (for example, computer integrated manufacturing and automation) and non-traditional manufacturing topics of interest to individual instructors (for example, printed circuit board manufacture, micromachining, solid freeform fabrication, etc.).

Lab Experience

To ensure that all students get to do manufacturing required a major change to the laboratory. As a result of a capital campaign, the department was able to purchase new material testing systems (for doing metal forming) and new machine tools. Previously, the laboratory for this class had one material testing system, one lathe, and one milling machine. We now have three material testing systems (two Tinius Olsen 60,000 lb and one Tinius Olsen 120,000 lb), six lathes (Emco Maier PC55 Turn), and six mills (Emco Maier PC55 Mill). Our lab section size is 12 students which means that the metal forming labs have 4 students per station, and the machining labs have 2 students per station.

Table 1 outlines the weekly laboratory topics. While the primary goal of the lab is to provide the opportunity for students to do manufacturing, additional goals include exposing students to manufacturing equipment and its operation; showing how part design impacts manufacturability; identifying factors (such as machine settings, mold design features, etc.) that influence part quality.

Table 1: Weekly Lab Topics

Safety
Measurement
Tension Test
Compression Test
Extrusion
Deep Drawing
Powder Metallurgy
Casting
Polymers
Rapid Prototyping
Turning (2 weeks)
Milling (2 weeks)

The first week's safety orientation includes general lab safety and machine tool safety. (As students learn to operate specific pieces of equipment during this and later courses, they receive additional safety training.) In the measurement lab, students learn to use handheld gages such as calipers and micrometers as well as a coordinate measuring machine, roundness tester, and profilometer. Measurement uncertainty and sources of error are a primary emphasis. The tension and compression tests demonstrate the generation of stress-strain curves.

The metal forming lab exercises (forging, extrusion, deep drawing, and powder metallurgy) have retained some of the data collection of the old lab but have added considerations of die design. Students record quantities like force and strain as was done in the past, but they now perform tests with several different dies. By doing this, they see the effect of such features as aspect ratio, die angle, corner radii, etc. With four students per machine, every student learns to operate the equipment and instrumentation.

The casting and polymer labs are demonstrations performed by our Materials Science and Chemical Engineering departments, respectively. The casting demo instructor demonstrates the making of a sand mold and pouring of the mold. He also presents molds and finished parts from investment casting, lost foam casting, and stack molding. In the plastics demo, students make parts via injection molding, extrusion, and blow molding. A more hands-on experience with casting and polymer processing is desirable and will be pursued in the future.

The turning and milling labs take place over multiple weeks. The turning lab provides an introduction to M&G programming as well as setting tool and work offsets. In the turning lab students make a part from a canned program that involves multiple tools. For the milling lab students create a solid model and then convert it to a tool path program. In the fall 2001 lab, students draw and machine the part shown in Figure 1. Three tools (end mill, ball end mill, and drill) are used.

In the rapid prototyping lab students create an STL file from the same solid model they mill. A 3D Systems Thermojet printer creates the part in plastic.

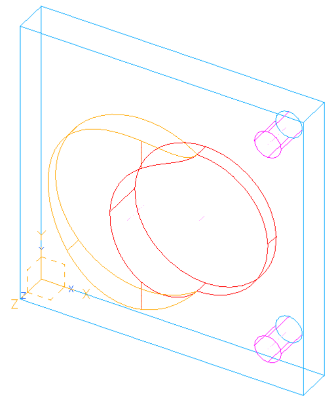

Figure 1: Part design for milling exercise

One of the challenges of implementing a more hands-on lab is that it requires more supervision. With 3 to 6 groups of students simultaneously operating manufacturing equipment, a single graduate teaching assistant would have difficulty managing. To deal with this, we recruited undergraduate teaching assistants. Although no compensation is offered, we have been able to recruit 12-16 students each semester. One or two undergraduates assist a graduate teaching assistant in nearly all lab sections. Their motivation has been to gain further experience operating machines. Given that approximately 125 students take this course each semester, these volunteers make a huge contribution to the smooth running of the labs.

Lessons Learned and Future Work

Not everything went smoothly in the first offering of this course, and a number of lessons were learned. One difficulty in broadening the course to include more product development and design issues is the lack of an adequate textbook. We supplemented the primary textbook[7] with notes and by placing a reference text[8] on reserve in the library. Another problem with the broader content is that it requires close communication with instructors of the freshman engineering courses as well as junior level design courses to ensure no significant gaps or overlap. In the first offering, the machining lab exercises required the students to spend a lot of time learning M&G code. Our intention, however, is for students to learn the capabilities of machine tools rather than become programmers. In subsequent semesters we have relied more on canned part programs and detailed step-by-step tutorial notes to lessen time spent learning machine code.

To improve the course, we plan to better integrate design concepts. Also, in the lab we plan to give students more opportunities to develop the solid modeling skills they learn in the freshman year. Finally, this course will further evolve as we assess student performance in the junior design classes and senior capstone design class.

Acknowledgments

This work was supported in part by NSF Career grant DMI9875251. The authors thank Mike LaCourt for his excellent work in developing the lab and in training the graduate and undergraduate teaching assistants that make it a success.

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