Integrating the Product Realization Process into a Mechanical Engineering Curriculum using Desktop Manufacturing Equipment

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Abstract

This paper describes how desktop manufacturing equipment can be used to help students experience the full Product Realization Process, and understand how production considerations inevitably impact the design process. Curriculum development has included the enhancement of an Introduction to Manufacturing course with demonstrations and laboratory exercises, the creation of a new hands-on elective course in Computer-Aided Manufacturing, and the addition of practical content in several design courses. It is shown that presentation of the production aspect of the Product Realization Process can be significantly enriched using relatively inexpensive desktop manufacturing equipment.

I. Introduction

The Product Realization Process (PRP) encompasses the entire cycle of production, from initial conceptual design to the finished manufacture of products. Key elements of the PRP have been studied from both academic and industrial viewpoints, and familiarity of engineering students with manufacturing methods has consistently ranked high among the PRP best practices.[1]

Mechanical engineering students are usually introduced to the PRP through courses in the design sequence, and perhaps an introductory manufacturing course. The various aspects of product design are usually well covered. However, students do not necessarily get the chance to see their designs actually produced -- thus completing the full product realization cycle. This makes it difficult to effectively teach how a product evolves from initial design concept through final production.

The trend in engineering education has been away from shop-based manufacturing courses, driven in part by factors such as equipment cost, liability and reduction of curriculum credit hours. However, as educators we are still confronted with the challenge of supplementing the theoretical aspects of analysis and design with substantive hands-on engineering experience.

Since full-sized production equipment can be prohibitively expensive, we have used portable desktop equipment in this project. Initial costs for individual apparatus have ranged from $4,000 to $20,000, depending on the sophistication of the machine and optional features. Ongoing costs have been limited thus far to consumables such as machining stock and plastics. The machines have been mounted on mobile workbenches so they can be configured to meet specific needs in various classes.

The major selection criterion for each machine has been that the apparatus must be able to produce real parts from real production materials. For example, a desktop CNC Mill or Lathe must be able to machine material such as brass and aluminum, as well as wax. Also, the plastics production machinery can be used to fabricate parts large enough to be of use in projects.

Using the desktop manufacturing equipment, we have developed a set of instructional modules to demonstrate key production processes through hands-on laboratory exercises in our Introduction to Manufacturing course. We have also created a new elective course in Computer Aided Manufacturing, built around the equipment, and enhanced several courses in the design sequence. The objective has been not only to achieve a distributed presentation of the PRP across our curriculum, but also to let students experience the production end of the PRP at close range.[2] Table 1 summarizes the curriculum development undertaken in the project.

Table 1. Curriculum Development Components.

COURSE	DESCRIPTION OF ACTIVITY
MENG 4319 Introduction to Manufacturing	Develop additional PRP course content centering on the desktop manufacturing equipment. Change to *required* course.
MENG 4324 Computer Aided Manufacturing	Create a new practice-based *elective* course to teach modern computer-driven manufacturing methods.
MENG 3309 Mechanical Systems Design (*required*) MENG 4214 Design Methodology (*required*) MENG 4320 Design for Manufacturing (*elective*) MENG 4415 Senior Project Design (*required*)	Enhance design sequence courses with hands-on capability enabling students to produce components and sub-assemblies for their design projects.

The curriculum development described here is a direct application of our department's strategic plan for addressing needs of local and regional industry, and is designed to produce Mechanical Engineering graduates who are equipped to step into today's industrial environment with a well developed understanding of product realization practice and modern manufacturing methods.[3]

II. The Desktop Manufacturing Equipment

Table 2 identifies the desktop equipment that supports the curriculum changes outlined in this paper. Some of the equipment (such as the CNC mill) was purchased by the Mechanical Engineering Department directly, and the rest was purchased with support from an NSF grant. It should be noted that the project has also taken advantage of apparatus already in the department, such as a Tinius Olsen tension testing machine and a fully equipped Lincoln welding booth.

Table 2. List of Desktop Manufacturing Equipment.

ITEM	DESCRIPTION	MAKE - MODEL
1	Rapid Prototyping System	Schroff - JP System 5
2	CAD/CAM Software	BOB-CAD Version 17
3	Desktop CNC Lathe	Light Machines - ProLight 3000
4	Desktop CNC Mill	MAXNC - Model 15
5	Injection and Blow Molding Machine	Amatrol - T9013 series
6	Vacuum Forming Machine	Formech - Model 300X
7	Laboratory Press with Heated Platens	Carver - Model 2089HD
8	Five-Axis Robot With Servo Gripper	CRS Robotics - Model A255
9	Metrology Instruments	Mitutoyo (misc.)
10	Optical Comparator	Suburban Tool - Master View

Item 1 was included because Rapid Prototyping has become a crucial part of the Product Realization Process in many industries, and because it is being introduced in more and more engineering programs.[4] The system we selected uses an additive process involving cut adhesive sheets. The Rapid Prototyping system, and the CAD/CAM software listed in Item 2, are used by students in conjunction with the department's CAD and Solid Modeling software (Solid Edge by Unigraphics Solutions) to perform virtual and real prototyping of components. Then, ready-to-run codes are exported to the CNC machines (Items 3 and 4) to cut the parts.

The plastics machinery listed in Items 5 and 6 enables students to study several types of plastic parts production. Moreover, the CAD/CAM--Rapid Prototyping--CNC process described above allows students to design plastic parts, then design and fabricate the molds or forms, and finally to manufacture the finished parts. This cycle of activity allows the full PRP, especially the production end of the process, to be exercised by the students.

The hydraulic press in Item 7 was selected primarily for curing composite lay-ups, but can also be used for a variety of processes where heat and pressure are required. The desktop industrial robot in Item 8 is of a type typically used to load and unload CNC machinery. We plan to use it in a simulated CIM workstation (including a student-designed ASRS system), as well as for demonstrating automatic parts handling for assembly. The metrology instruments, which comprise Items 9 and 10, allow students to evaluate the dimensional accuracy of various processes and machines, conduct tolerance studies and learn quality control practices.

Figure 1 shows a schematic of the production end of the PRP, and indicates how the equipment can be used to study the steps involved. Here, the design process has led to a CAD representation of the part being developed. The component can be analyzed and rapid-prototyped at this stage. Then, CAD/CAM software can be used to generate the CNC machine codes to cut the tooling required to make the part. Finally, the production run is executed (for example, by injection molding). The finished part is then available to next step in assembly (robotic parts handling can be introduced here). Metrology is used to check the dimensional accuracy of the product. Note how feedbacks from the manufacturing process may be used to adjust design specifications.

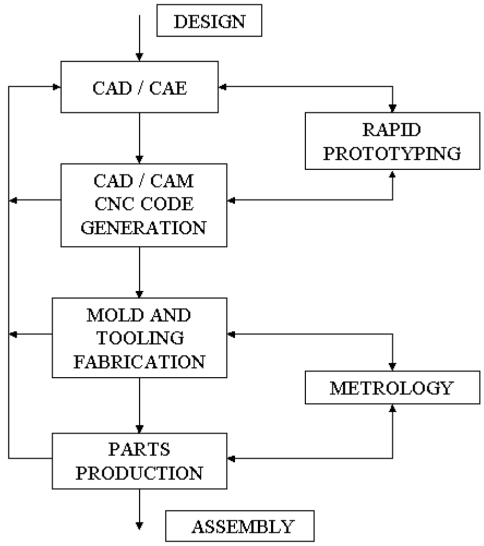

Figure 1. Schematic Showing the Production End of the PRP.

The CNC Mill shown in Figure 2 and the Injection Molding Machine shown in Figure 3 are representative examples of the desktop manufacturing equipment used in this project. The equipment demonstrates real manufacturing operations to students, while being compact and relatively affordable. Desktop CNC mills have been found particularly useful by a number of engineering programs for teaching PRP principles, including work in freshman courses.[5]

Figure 2. Desktop CNC Mill.

Figure 3. Desktop Injection Molder.

III. Curriculum Changes

Introduction to Manufacturing. Our enhanced Introduction to Manufacturing course (MENG 4319) was taught for the first time in the Fall semester of 2000 as a senior-level *elective*. The course content consists of a typical survey of manufacturing processes. However, the desktop equipment allowed us to enrich the course with several hands-on laboratory exercises and demonstrations. The additional modules developed for the course are listed in Table 3.

Table 3. Modules for the Introduction to Manufacturing Course.

MODULE	DESCRIPTION
Material Properties	Understanding material properties and strain hardening in metal forming operations.
Plastics and Composites	Injection molding, vacuum forming and composite parts production.
CNC Mills and Lathes	The metal removal process, and an introduction to CAD/CAM and CNC machinery.
Metrology	Introduction to measurement, tolerances and quality control.
Welding	Introduction to fabrication and assembly methods, including accuracy of the process.
Rapid Prototyping	Art-to-Part. Evaluating component designs prior to manufacturing. The CAD/CAM connection.
CIM and Robotics	Introduction to robotic parts handling and automation.

Each module consists of either a hands-on exercise, or a close-range demonstration. The modules were introduced after the related lecture material and text book[6] assignments had been completed. A semester project was assigned in the course that required each student to produce a part on the lathe and mill using CAD to design the tool paths and CAD/CAM software to automatically generate the CNC codes.

We have just completed a redesign of our Mechanical Engineering curriculum, reducing the required number of credits from 140 to 128. The new curriculum will start officially in Fall, 2001. As part of the redesign, Introduction to Manufacturing will become a two-credit r*equired* sophomore course (MENG 2219). The new course will have one hour of lecture and three laboratory hours per week. This change was implemented so students can become familiar with manufacturing processes early enough in the program for the experience to positively impact their later course work (especially in courses where elements of the PRP are presented).

<u>Computer-Aided Manufacturing.</u> Computer-Aided Manufacturing (MENG 4324) is a new *elective* in the Mechanical Engineering curriculum that will be presented for the first time in the Spring 2001 semester. Consequently, at the time of writing this paper the course has been designed, but has not yet been taught. A brief outline of the course content is as follows:

- CAD and Solid Modeling used to design mechanical components
- Automatic generation of Rapid Prototypes
- Automatic CAD/CAM generation of CNC codes

- Machined parts fabrication on CNC mill and lathe
- CAD--Rapid Prototyping--CAD/CAM plastic part and mold design
- CNC machining of molds for plastic parts
- Injection molding and vacuum forming of parts
- Work cell layout and automatic parts handling using the Mill, Lathe and Robot
- Computer monitoring of production machinery

It can be seen that a broad spectrum of computer-aided design and manufacturing topics will be addressed. The course will be project-based, and will concentrate on practical utilization of the equipment and software. Assignments will include a team-based project requiring the finished production of plastic parts, as well as an individual research paper exploring in depth one of the key topics in the course.

Design Sequence Courses. An important part of our curriculum enhancement efforts has been to utilize the desktop manufacturing equipment in the design sequence, at least for component fabrication. Without the means of following through with actual parts production, integration of the PRP into the curriculum could not be meaningfully achieved, since it would not be possible for students to experience the true "realization" of their design efforts.[7] Table 4 lists the design sequence courses in which the equipment has been used.[8]

Table 4. Summary of Design Courses Impacted by the Project.

COURSE TITLE	MANUFACTURING TOPICS
MENG 3309 Mechanical Systems Design (*Required*)	All Topics, as they Relate to Fabrication of Components
MENG 4214 Design Methodology (*Required*)	All Topics, as they Relate to the Product Realization Process
MENG 4320 Design for Manufacturing (*Elective*)	High Volume Production, Especially Injection Molding
MENG 4415 Senior Project Design (*Required*)	All Topics, as they Relate to Fabrication of Components

The equipment has allowed students in Mechanical Systems Design and Senior Project Design to fabricate a variety of parts for design projects, with the assistance of our Fabrication Laboratory manager, Mr. Jim Mills. This means that more designs can actually be constructed, rather than being "paper designs." Design Methodology presents a comprehensive view of the design process. The equipment has allowed a hands-on presentation of the full PRP, with special emphasis on conceptual design using CAD and Rapid Prototyping. Design for Manufacturing concentrates on design methods for high volume production. The Plastics Production equipment has been especially useful to support this set of topics.

Some of the equipment has also been used in the Design Graphics module of our freshman Fundamentals of Engineering sequence (ENGR 1300). As part of their team-based semester design project, students were taught how to generate rapid prototypes directly from CAD. The prototyped parts were then used as actual components in their designs.[9]

IV. Implementation and Evaluation

In order to ensure that our curriculum enhancements appropriately address aspects of the PRP that are relevant to industry, we have enlisted the help of local industrial partners to assist with planning and evaluation of the curriculum changes. The partners were invited to identify topics that should be included in the affected courses. Besides confirming that the proposed suite of hands-on PRP exercises are relevant to employers in the East Texas region, the partners added several key points, covering engineering activities at the project level:

- Define the criteria for success before starting a project
- Be prepared to incorporate improvements suggested in design reviews
- Be prepared to quickly identify and solve a wide variety of problems
- Understand business practices (as well as engineering)

Project-level planning is strongly stressed in our curriculum, especially in the design courses. In our curriculum development we have capitalized on the opportunity to build students' understanding of defining project completion by requiring the submission of finished parts and not just job plans or drawings. The new course work has also helped develop their appreciation of the many skills and resources required to produce a viable product in a business enterprise.

As part of our project assessment we have obtained results from a survey of students completing the Introduction to Manufacturing course in the Fall of 2000. They were asked to rate the course, and the seven new modules, on a scale from one (least favorable) to five (most favorable). The average scores are presented in Table 5.

Table 5. Student Survey Results from the Introduction to Manufacturing Course.

MODULE	AVG. SCORE
Material Properties	3.4
Plastics and Composites	3.8
CNC Mills and Lathes	4.8
Metrology	3.6
Welding	3.8
Rapid Prototyping	4.0
CIM and Robotics	3.8
Overall Course Rating	4.8

It can be seen that the student response to the overall course is very favorable, with the CNC Machining and Rapid Prototyping modules getting the highest marks. We have also noted that the Materials Properties and Metrology modules did not score as well, perhaps due to the fact that there were equipment malfunctions in both of these laboratory sessions. We plan to reevaluate the approach taken in these modules so that improvements in both content and delivery can be made.

Final evaluation of the project will be at the end of the Spring 2001 semester. A panel consisting of our industrial partners, a Mechanical Engineering faculty member from another university in our region, a faculty member from the UT-Tyler College of Engineering who was not involved in the project, and students from the affected courses will review implementation of the Product Realization Process in our curriculum. We will specifically solicit suggestions for improving our presentation of the PRP. We will also look for ideas to further our utilization of the desktop manufacturing equipment in courses where engineering theory and analysis can be enhanced by a practical hands-on dimension.

V. Conclusions and Future Work

This project has added a practice-based dimension to our curriculum that will enhance the skills and employability of our graduates. Employers in East Texas have indicated that new engineers who have a practical understanding of Product Realization issues are better able to "hit the ground running." From the enthusiastic feedback we have received from students, and with the assistance of our industrial partners, we are confident that our curriculum contains an effective presentation of the PRP, from conceptual design and project-level planning through actual parts production using modern manufacturing methods.

At the conclusion of our project, in Summer 2001, it is our intent to publish a "Guide for Using Desktop Manufacturing Equipment to Demonstrate the Product Realization Process in a Mechanical Engineering Curriculum." This resource will consist of a handbook of practical demonstrations and laboratory exercises, examples of how desktop manufacturing equipment can be used to enhance content in courses addressing Product Realization issues, and a vendor list that identifies a spectrum of desktop manufacturing equipment. The guide will be available in hard copy form, and will be mailed to other small mechanical engineering programs in the country. It will also be posted in PDF format on the UT-Tyler College of Engineering web site: http://www.eng.uttyler.edu/.

VI. Acknowledgements

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