2006-2096: INCORPORATING DESIGN IN A MANUFACTURING ENGINEERING TECHNOLOGY CURRICULUM

Somnath Chattopadhyay, Ball State University

SOM CHATTOPADHYAY is currently the coordinator of the Manufacturing Engineering Technology Program at Ball State University. His primary teaching interests are Design, Materials, Manufacturing, Engineering Physics and Engineering and Technology Education. He has taught mechanical design, materials and manufacturing at a number of universities in the United States and the Middle East. For one year he taught freshman engineering at Indiana University-Purdue University, Fort Wayne, Indiana. His areas of research are design theory and methodology, pressure vessel design and analysis, and dynamics of mechanical and electromechanical systems. He serves as a consultant to Westinghouse Electric Company, and is a registered professional engineer. He recently authored a text on Pressure Vessel Design. He received his Ph.D. in Mechanical and Aerospace Engineering from Princeton University.

Incorporating Design in a Manufacturing Engineering Technology Curriculum

Abstract

The typical manufacturing technology program focuses on manufacturing processes (metals and plastics) along with computer aided design which is primarily geared to drafting; this is supplemented further by courses in automation and computer integrated manufacturing. As a part of the curriculum, there are courses on mechanics of materials and engineering materials (metals and plastics), and also on electronics and instrumentation. There is some emphasis on design for quality through courses in quality control and design of experiments. The capstone projects do however, focus on various aspects of design, namely design for manufacturability as well as design for assembly. However, the perspectives of design, as such are not uniformly and strictly emphasized in a traditional manufacturing engineering technology curriculum. Furthermore, in the program at the author's institution, there is no course on design of mechanical elements. The objective of this paper is to propose the incorporation of design across the curriculum for a typical manufacturing engineering technology program. It is fairly easy to incorporate design concepts in the mechanics of materials course (typically in the junior or senior year), emphasizing the issues of design for strength. The other courses that the issues of design become significantly important are in the ones involving metals and plastic processing. The aspect of design with uncertainty in material properties as well as other unknown parameters may be satisfactorily incorporated in courses on quality and design of experiments. Finally, the engineering design process and the corresponding problem-solving methodology must be strictly enforced in the senior level capstone experience in a manufacturing engineering technology curriculum. The basic elements of this concept as well as "design thinking" must originate at the cornerstone freshman design course and permeate through the sophomore, junior and senior classes. All these proposed enhancements and modifications to the curriculum are highlighted in this paper.

Introduction

The manufacturing engineering technology (MET) at the author's institution is accredited by the Accreditation Board of Engineering and Technology (ABET). The ABET criteria[1] require that the students graduating from an engineering technology program demonstrate "an ability to apply creativity in the design of systems, components or processes appropriate to the program objectives." Design by its very nature is broad in scope and draws on creative talents, management shills and skills and knowledge of those involved. Furthermore design problems are not truly deterministic, and that is something the students do not see in their basic courses on sciences and mathematics. Design problems could have many solutions and one has to pick the optimum solution in terms of the criteria and requirements for a given situation. The design problems are open-ended and require decisions based on incomplete information. The Manufacturing Engineering Technology program at the author's institution is currently being actively reorganized to include the elements of design and how it can be strategically implemented across the curriculum especially in some key courses.

It should be noted however, that the engineering technology programs are typically different from the engineering programs in being more applied and hands-on in nature. The implementation of design is therefore quite challenging in an engineering technology program. This is particularly significant for the program at the author's institution where there is no specific course on design of mechanical elements. The students are of course made aware of the fact that analyses are frequently required as part of the design process to size components or to verify that the design criteria are met. However there is no formal course where the students are asked to investigate failures, examine ways to improve processes, as well as to apply the engineering analysis skills so typical in the formal design process. Therefore the strategy implemented was to target these concepts in all the courses throughout the curriculum. The students are constantly reminded that design is fundamental to all forms of engineering and engineering technology. Design does bring realistic applications into the curriculum and as such can help students pull fundamental technical concepts together and adequately bridge the gap from theory to application. If the educators in the engineering technology arena who are competent in applying rigorous approaches to solving new technical problems, they should provide students with the tools for solving the types of open ended problems the program graduates will face in the workplace. Therefore we try to incorporate the design aspect carefully in the existing courses without doing a total overhaul of the program. We felt this aspect could be satisfactorily implemented through creative problem solving activities and design projects in various courses within the curriculum.

Within the engineering curricula, the educators have come to a conclusion that it is not possible to teach the broad subject of design in a single course or even the capstone design project. Fronczak and Webster[2] and Tompkins[3] describe a sequence of courses to be taken by a specific engineering major, biomedical engineering from the sophomore year to the senior year. Sheppard and Gallois[4] describe a "design spine" that run through all the eight semesters of the freshman year through the senior year, with the purpose of achieving greater integration with the science and engineering science courses. In this paper a similar framework has been used for the Manufacturing Technology program at author's institution which does not have the basic design of machine elements course.

The Structure of the MET Program at Author's Institution

For this program it is required to take 14 courses (42 hours) in the program and four technical electives (12 hours). The fourteen courses are:

<u>Freshman Year</u>

- Technical Design Graphics
- Introduction to Manufacturing Industries

Sophomore Year

- Computer-aided Design
- Industrial Plastics
- Machine Tool Processing
- Manufacturing Materials
- Applied Quality Control
- Industrial Electronics

Junior Year

- Automation and CIM Systems
- Applied Statics
- Fluid Power: Hydraulic Systems
- Industrial Control and Digital Instrumentation

Senior Year

- Applied Strength of Materials
- Manufacturing Planning and Control

In addition the students are required to take 4 additional courses as technical electives, which are;

Junior Year

- Plastic Product Design
- Plastic Production Systems

Senior Year

- Design of Experiments in Manufacturing
- Projects in Computer-aided Manufacturing

The last course is the capstone course typically taken by the seniors during the last semester of the senior year and that makes it a required course for the program. This capstone course is a semester long course and there are plans for making it a two semester course in the future.

The general program requirements include the basic science and mathematics courses and an introductory course in computer science in which the students learn the *"C"* language.

One of the characteristics of the program is its significant emphasis on computer aided design, and statistics. There is also some emphasis on plastics primarily through the technical electives. The students can opt for a minor in Design Technology or one in Plastics Technology.

Strategies for Implementing Design across the Curriculum

The courses throughout the MET curriculum in which the elements of design are to be introduced are indicated in Table 1. Some of the courses already have significant elements of design in them, while in others the levels are low and some cases the design element is non-existent. The objective is to have a fair to heavy emphasis of design in all of the courses in the curriculum.

A. Freshman Year Courses:

The freshman year courses within the program currently are Introduction to Manufacturing Industries and Technical Design Graphics.

We will integrate elements of design through the introductory course, presently called Introduction to Manufacturing Industries. The laboratory experience in this course at this time involves organizing, staffing, and operating a model manufacturing enterprise. The students are required to have limited fabrication skills for this course.

The course would be renamed Introduction to Modern Manufacturing. This course is truly a "cornerstone (design) course," as coined by Dym[5]. This important first year cornerstone course should have the following objectives:

- enhance student interest in engineering and engineering technology
- enhance student retention in MET program
- motivate learning in upper class MET courses

In this course the freshmen students would be exposed to some flavor of what manufacturing engineers actually do. We would additionally include in the course and introduction to the engineering design process (see for example, Dieter[6]). The steps in the engineering design process will be highlighted and will be contrasted to the scientific method that the students are familiar through their science and math courses. The three phases of design, namely conceptual, embodiment and final design will be outlined which will be followed by each being broken down into successive steps. For example, the important phase of conceptual design will include need recognition, problem definition, information gathering, search for a solution and the implementation of the specific solution. This aspect will be reinforced using their individual project examples. The additional focus should be on design and fabrication of hardware to meet a specific set of requirements, emphasizing the concept of design for manufacturability.

The second freshman course is Technical Design Graphics. This contains the theory and practice of production drawing as well as an introduction to design. A part of the course involves sketching, which is truly an integral and important part of the design process. Sketching forms bases for revising and refining ideas, generating concepts as well as for facilitating problem solving. As a part of the course there is a team design project. The aspect of design that is being additionally proposed is to mimic how a design project is conducted in industry. This requires the development of project plans and schedules. This also requires the development of 3D CAD component and assembly drawings done using the software Unigraphics[7]. There is an emphasis on creativity and ingenuity as a part of the team design project, which also requires oral and written communication.

B. Sophomore Year Courses

Of the courses during this year there is a course on computer aided design along with two courses on materials, one on industrial plastics and the other on metallic materials. Besides these, there are courses on quality control, machine tool processing and industrial electronics.

The course Computer Aided Design is an important design course where the focus is on dimensioning and tolerancing. Also included in this course is the important concept of rapid prototyping.

In the course Industrial Plastics, a laboratory based course, we plan to incorporate a design project to design molds for a specific part used in injection molding process. The students would be involved in a reverse engineering process where they would confirm their findings with the actual die in the injection molding machine used in the laboratory.

The course Manufacturing Materials focuses on metallic materials. Here the aspect of materials selection, an important design activity is adequately reinforced. This is obvious as we observe that material costs comprise over half or more for most products manufactured in today's automated manufacturing environment. Therefore, a rational process for material selection needs to be incorporated. Furthermore, in keeping with the philosophy of concurrent engineering, the innovative choice of material must be done at the conceptual level of any engineering project. A number of methods using computer based database has been suggested for implementation in the materials course, within the manufacturing engineering technology program. For this course a module has been introduced which lets the students use a specialized software, the Cambridge Engineering Selector (CES) EduPack[8].

One of the important courses during the second year of study is Machine-Tool Processing. One of the important modifications to this course would involve exposing the students to the design of cutting tools and associated strength issues. They would also be oriented in the dynamics and control issues associated with manufacturing, such as machine tool vibration and chatter. The other modification would be addressing the important issue of design for manufacturability.

In the course Applied Quality Control, which deals primarily with statistical inference, the design based on statistical decision making process may be highlighted. One of the things that could be stressed in this course is that an engineering design is often conducted with imperfect models, incomplete information along with ambiguous objectives. The issue of factor of safety as a byproduct of dimensional and material property variability could be introduced in terms of uncertainty in statistical terms. Quality Function Deployment (QFD) is the important design method that evolves from this course.

In the course Industrial Electronics the process of selecting motors for machinery drive application as an important design item. In addition, a number of problem solving activities can be introduced focusing on approximation skills.

C. Junior Year Courses:

There are courses on automation and CIM, on fluid power and on industrial control and digital instrumentation. There is an important course on statics. Three courses in the material processing area are all electives: one in casting and welding and two in the general area of plastics.

In the course Automation and CIM Systems the concept of system dynamics can be effectively incorporated. One of the skills that could be cultivated in the course is to anticipate the unintended consequences arising from the interactions among the multiple parts of a system. This skill is essential for designing complex manufacturing systems and managing the design process. In addition, for this course plans are under way to have team projects involving the design of a robotic assembly system. In these projects, the students would be required to determine project goals and deadlines, and also to produce final oral and written reports.

The course Applied Statics is viewed as one where a number of creative problem solving can be introduced. One of the skills that may be developed is that of approximation or making realistic estimates to the solutions to real world statics problems.

The courses Plastic Product Design and Plastics Processing (both electives) focus on the important issues of product design and design for processing. The issues of design for manufacturability and design for assembly could be reinforced in these courses. Similar emphasis could be given to the elective course Casting and Welding.

In the course on Fluid Power we are soliciting team projects from local industry through the industrial advisory board in which the student teams will participate and produce final oral and written reports. A number of activities are directed towards creative problem solving.

In the course Industrial Control and Digital Instrumentation, the design of control systems for a device such as a CNC machine tool could be treated as an important design item. In addition, a number of problem solving activities can be introduced focusing on approximation skills.

D. Senior Year Courses

The courses on strength of materials, manufacturing planning and control, design of experiments (an elective) and the capstone course constitute the senior level courses.

Table 1
Curriculum Map for Design in a Manufacturing Engineering Technology Program

Year	Course	Design Elements Input	Medium
1	Introduction to Manufacturing Industries (161)	Engineering design process Design for manufacturability	Activities Projects
	Technical Design Graphics (105)	Sketches of design concepts, visual communication	Activities Projects
2	Computer-Aided Design (205)	Detail design, product design, visualization	Activities Projects
	Industrial Plastics (225)	Design of molds, process design	Activities Projects
	Machine Tool Processing (233)	Tool design , Design for manufacturability	Activities Projects
	Manufacturing Materials (262)	Material selection, materials in design, failure studies	Activities Projects
	Applied Quality Control (265)	Robust and Quality design, design under uncertainty, QFD	Activities Projects
	Industrial Electronics (270)	Motors/accessories selection, creative problem solving	Activities Projects
3	Automation and CIM Systems (301)	System design, creative problem solving, robot design	Activities Projects
	Applied Statics (307)	Creative problem solving	Activities Projects
	**Plastics Product Design (325)	Product design , Design for manufacturability	Activities Projects
	**Plastics Production Systems (326)	Process design, design for plastic processing	Activities Projects
	**Casting and Welding (334)	Process design, design for casting and welding	Activities Projects
	Fluid Power-Hydraulic Systems (340)	Creative problem solving, system design	Activities Projects
	Industrial Control & Digital Instrumentation (371)	Design of control systems, creative problem solving	Activities Projects
4	Applied Strength of Materials (407)	Design for strength, fatigue, creative problem solving	Activities Projects
	Manufacturing Planning and Control (463)	Economic decision making, legal and ethical issues, project management	Activities Projects
	**Design of Experiments in Manufacturing (425)	Experimentation, design under uncertainty	Activities Projects
	Projects in Computer-Aided Manufacturing (473)	Project definition, planning, cost estimating, tracking and monitoring resources, detailed design, fabrication, testing, documentation and oral presentation, Design for Assembly, Design for Environment, Design for Safety	Capstone Project, team building

** Indicates an elective course

The design elements in the course Applied Strength of Materials can be addressed through a number of projects involving yield/ultimate strength and fatigue strength. In these activities the students realize that prescribing design specifications without careful strength calculations can lead to inadequate design. A number of activities related to creative problem solving can be introduced along with a development of approximation skills.

The crucial course in this year is Manufacturing Planning and Control is a course in which the workplace environment is brought into perspective. Some of its emphasis could be directed to design problems along with the economic decision making and ethical issues. The important design element of project management is addressed here.

The elective course Design of Experiments in Manufacturing covers statistical methods for decision making and is a logical extension of the sophomore level course, Applied Quality Control. Modifications to this course could include modern computational tools to support probabilistic thinking.

The most important place where the key elements of design are introduced is of course in the capstone course, Projects in Computer Aided Manufacturing. Presently a one semester course, this is now being redesigned for a two-semester sequence. The focus on the first semester would be on project definition and planning, conceptual and preliminary design leading to 3D part and assembly drawings with dimensional details. Also included will be the estimation of costs and preliminary design oral presentation and report. It is hoped that these projects would be obtained from the local industry.

The second semester would see the completion of the capstone project with an emphasis on tracking and monitoring resources, detailed design, fabrication and testing. The final oral presentation and a formal report would be required. Capstone projects present an opportunity for students to independently complete a significant project and this activity culminates our effort as engineering technology educators to incorporate design into the baccalaureate program in Manufacturing Engineering Technology.

A significant amount of effort in the classroom will be directed to the important issues of design for manufacturability and design for assembly. In addition, a number of guest speakers will be invited to address the issues of design for environment as well as design for safety.   The standard textbooks used for the capstone course are Dieter[6] and Hyman[9].

Conclusions

This paper has presented the approach used for a Manufacturing Engineering Technology program to integrate design content throughout the curriculum. The strategy employed includes the incorporation of problem solving activities to stimulate design thinking and participation in design projects with the objective of showing the students how the technical content of a traditional course is used to design hardware. The approach has the advantage that it can be implemented by adjusting course content without completely revamping the overall curriculum. Throughout the curriculum the issue of design thinking will be introduced and reinforced starting with the cornerstone course and culminating with the capstone course.

Bibliography

1. ABET (2000). http://www.abeLorg
Follow the accreditation link to the engineering technology accreditation criteria.

2. Fronczak, FJ., and Webster, J.G., "A Series of Design Courses in Biomedical Engineering," *Proceedings of the 1999 ASEE Annual Conference and Exposition.*

3. Tompkins, W. J., "Using Design as a Backbone of a BME Curriculum," *Proceedings of the 2001 ASEE Annual Conference and Exposition.*

4. Sheppard, K, and Gallois, B., "The Design Spine: Revision of the Engineering Curriculum to include a Design Experience each Semester," *Proceedings of the 1999 ASEE Annual Conference and Exposition.*

5. Dym, C. L., "Learning Engineering Design, Languages and Experiences," *Journal of Engineering Education,* Vol. 88, No. 2, 1999, pp. 145-148.

6. Dieter, G. E., *Engineering Design: A Materials and Processing Approach*, New York, McGraw Hill, 3rd Edition, 2000.

7. Samuel, S., Pragada, A., and Baksi, G., *Advanced Unigraphics NX2: Modeling and Assemblies: A Project Oriented Learning Manual*, Design Visionaries, Inc. Can Jose, CA, 2004.

8. *CES EduPack Selection Software*, Granta Design Limited, Cambridge, UK, 2005.

9. Hyman, B., Fundamentals of Engineering Design, 2nd Edition, Upper Saddle River, NJ, Prentice Hall, 2002.