AC 2009-513: IMPLEMENTING A DESIGN AND MANUFACTURING TRACK IN A MECHANICAL ENGINEERING PROGRAM

Xiaolin Chen, Washington State University, Vancouver

Dr. Xiaolin Chen is an Assistant Professor of School of Engineering and Computer Science at Washington State University Vancouver. She received her Ph.D. from the University of Cincinnati and her M.S. and B.S. from Shanghai Jiao Tong University, China. Her teaching and research interests include computational mechanics, finite element and boundary element methods, advanced materials modeling & characterization, and manufacturing process simulation.

Dave Kim, Washington State University, Vancouver

Dr. Dave (Dae-Wook) Kim is an Assistant Professor of School of Engineering and Computer Science at Washington State University Vancouver. He received his Ph.D. from the University of Washington, Seattle, and his M.S. and B.S. at Sungkyunkwan University, Korea. His teaching and research interests include manufacturing processes, composite materials, and mechanical behavior of engineering materials.

Implementing a Design and Manufacturing Track in a Mechanical Engineering Program

Washington State University Vancouver Mechanical Engineering Program provides students with a solid foundation upon which they can build to meet the challenges associated with their individual career paths and to adapt to the rapidly changing technologies. To that end, the creation of cohesive course sequences as an opportunity to implement the reform was identified. Three cohesive course sequences, so called "track", have been offered to the students. The Design and Manufacturing track provides seven closely-integrated courses to help students learn how to apply engineering fundamentals to practical design and manufacturing problems. The track courses include: Engineering Materials, Numerical Analysis, Manufacturing Processes, Machine Design, Computer-Aided-Engineering, Advanced Manufacturing Engineering, and Manufacturing Systems. The track courses will not only cover basic principles in product design and manufacturing, but will also instill problem-solving skills, teamwork skills, and hands-on experiences. Both software technologies (CAD/CAE/CAM) and modern hardware tools (RP, CNC, etc) have been implemented into the track courses. Upon completion of the seven track courses, students can receive the certificate from the school. This paper presents details of planning and implementation of such a curriculum development activity in design and manufacturing within the mechanical engineering curriculum. Overall student experience and lessons learned in developing such a curriculum are also discussed.

1. Introduction

Current mechanical engineering curricula are originated from a century-scale "grand scientific paradigm": mechanics in the 17^{th} and 18^{th} centuries and thermodynamics in the 19^{th} century. These origins have been reflected for well over a century in Mechanical Engineering (ME) curricula [1]. In January 2002, The National Science Foundation chartered a workshop on "Redefining Mechanical Engineering" to explore new possibilities for ME education. Recommendations were made to streamline and update ME curricula by introducing emerging knowledge related to micro/nano technology, product design and realization and etc. and exposing students to computational methods and design practices employed by practicing engineers [2]. To keep up with the national trend in ME education, we plan to implement three track areas in the program: (1) Mechatronics; (2) Design and Manufacturing; and (3) Micro/Nanotechnology. With the completion of a track area, the graduates can earn the certificate of completion from the chair of the school.

Manufacturing is strategic for the United States' global competitiveness and relates to national wealth indices. According to Industry Week on-line magazine, manufacturing generates 4.5 times more jobs than retailing and represents 80 percent of all world trade. The economic success of manufacturing; however, hinges on successful engineering designs. Today, mechanical engineers face the challenge of realizing a product design with increased complexity and a shortened life cycle under intense global competition. Studies [3-6] suggest that a career in product design and development has been one of the major goals for students choosing mechanical engineering majors. Seamless design, analysis, and manufacturing capabilities are rapidly being adopted by industry as a part of standard engineering practice. However, mechanical engineering curricula tend to overlook design and manufacturing relationships until the senior capstone course sequence [6]. A track area of Design and Manufacturing offered in a mechanical engineering program may provide a viable solution to augment a conventional ME curriculum. This paper presents details of planning, managing and implementing such a curriculum development activity in design and manufacturing under the mechanical engineering curriculum. This novel effort is rooted in a shared nationwide vision and a wholehearted support from our students and the local industry.

2. Design and Manufacturing Track Need Analysis

In southwest Washington, a variety of local business and industries ranging from aerospace, marine, machinery & equipment, lumber & wood products to electronics devices provide ME graduates abundant employment opportunities in the practice of product design and manufacturing. Desirable local employees equipped with contemporary knowledge of micro-fabrication, computer-aided design/engineering/manufacturing, advanced materials and modern product design and realization are in high demand. The topics covered in a traditional ME curriculum needs to be updated in response to the local needs, modern-day circumstances and the changing role of mechanical engineers. In order to identify the gap between the traditional curriculum topics and the changing role of mechanical engineers in the design and manufacturing area, faculty members in the design and manufacturing track conducted a study on engineering curricula and had a series of meetings with the local industry leaders, which include Industrial Advisory Board (IAB) members and alumni of the program. Table 1 shows the traditional ME curriculum topics, a changing role of ME in the school target region, and the gaps between two.

Table 1. Illustration of the gaps between the traditional ME curriculum and the changed role of mechanical engineers in Design and Manufacturing

<table>
<tr><th>Traditional curriculum topics</th><th>Gaps</th><th>A changing role of mechanical engineers</th></tr>
<tr><td>Metallic materials</td><td>Polymer materials,
Composite materials</td><td rowspan="9"><u>Local needs</u>
Electronics product industry
Polymer structure design and manufacturing
Microfabrication processes
Aerospace industry
Precision machining processes
6 sigma / lean manufacturing
Composite structure design and fabrication
Heavy truck industry
Assembly processes
Aluminum structure design
<u>New direction of ME education</u>
Nanotechnology
Life science
Modern computing
Interdisciplinary/international collaborations</td></tr>
<tr><td>Ferrous metallic materials</td><td>Non-ferrous metallic such as aluminum</td></tr>
<tr><td>Conventional design</td><td>Reverse engineering and redesign
Design for recycling</td></tr>
<tr><td>Stand-alone design courses</td><td>Integration of design, simulation, optimization and manufacturing</td></tr>
<tr><td>Metallic material processes</td><td>Polymer processing,
Composite fabrication</td></tr>
<tr><td>Manual machine tools</td><td>CAD/CAM
CNC machine tools</td></tr>
<tr><td>Part shaping processes (i.e., casting, forming)</td><td>Assembly processes</td></tr>
<tr><td>Statistical Process Control</td><td>6-sigma, lean manufacturing</td></tr>
<tr><td>Traditional prototyping</td><td>Rapid and virtual prototyping</td></tr>
</table>

Representatives from the local industry are in unanimous agreement on exposing our students more to the computer-aided working environment in the new era of engineering design and manufacturing. They need well-rounded graduates with the “big picture” in mind and a good balance of theory and practice for a variety of things from materials, costs, design and manufacturing processes to engineering project management. Local industry leaders commonly emphasize that 21st century mechanical engineers should have real understanding of lean enterprise/manufacturing. The mechanical engineer must have a solid background in engineering principles, as well as business acumen and personal presence. Therefore, the sequence will also introduce the theory, concepts, policies, procedures and steps of lean manufacturing. Students will learn how to determine the major causes that create “waste” in factories and how to minimize or eliminate them.

3. Design and Manufacturing Track Design and Implementation

In order to fill the gaps between traditional ME curriculum and the contemporary needs of mechanical engineers in the local region, three track courses have been implemented into the curriculum. Three courses chosen for the track were 1) Introduction to Manufacturing Systems (MECH425), 2) Advanced Manufacturing Engineering (MECH476), 3) Computer Aided Engineering (MECH 485). The short description of each course is following:

1) Introduction to Manufacturing Systems (MECH425): Traditional and contemporary tools used to support direct manufacturing processes in a manufacturing enterprise. Topics covered: decision analysis, planning production processes, manufacturing facilities, production planning, inventory management, statistical process control, JIT, and TQM.

2) Advanced Manufacturing Engineering (MECH476): Advanced topics in manufacturing processes, including interrelationships between the properties of the material, the manufacturing process and design of components. Topics covered: geometric dimensioning and tolerancing, polymer processing, ceramic processing, composite processing, nontraditional machining processes, rapid prototyping, and lean manufacturing.

3) Computer Aided Engineering (MECH 485): Introduction to the use of finite element techniques in engineering product design and analysis; basic concepts and applications in CAE. Topics covered: finite element formulation, bar elements and truss analysis, beam and frame analysis, idealization, symmetry and finite element modeling techniques, plates and shell analysis, solid elements and three-dimensional stress analysis, structural vibration and dynamics, thermal analysis, design optimization, bulking failure and fatigue analysis.

Figure 1 shows the ME program curriculum related to the design and manufacturing track.

Design and Manufacturing Track Curriculum Chart

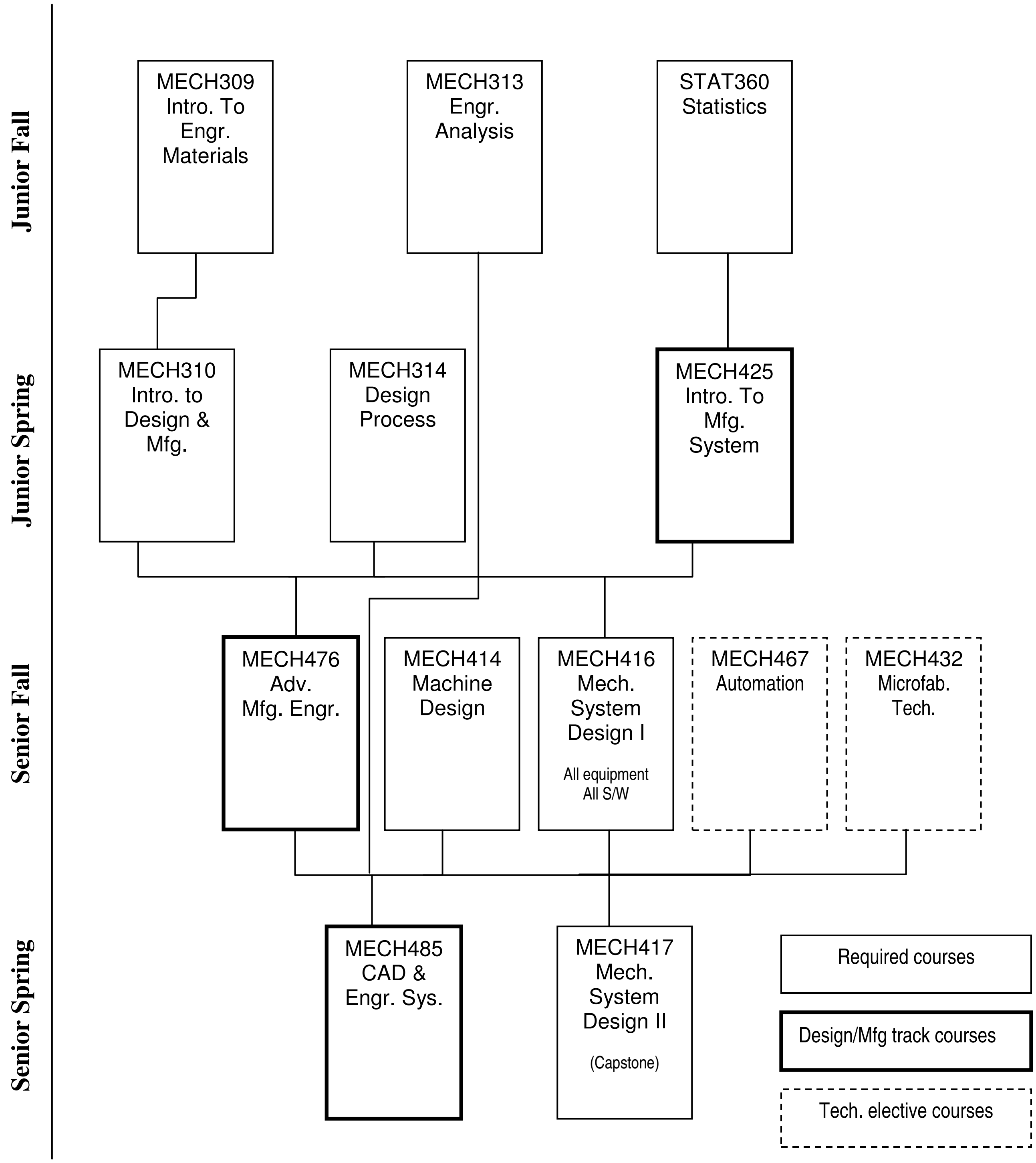


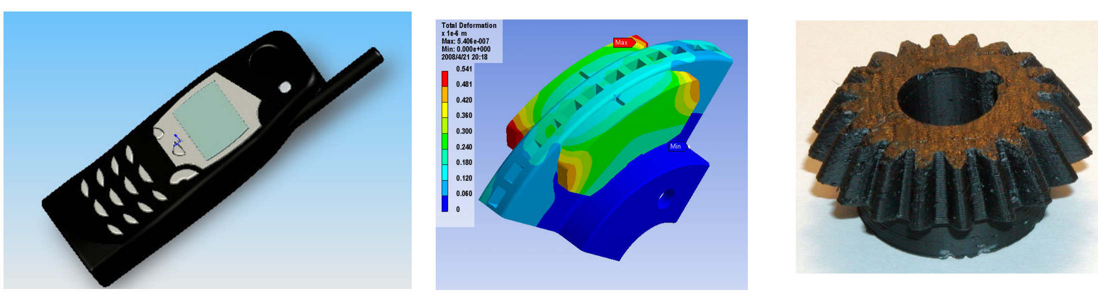
Figure 1. WSU Vancouver Mechanical Engineering curriculum related to the Design and Manufacturing Track.

The following three objectives guide us in the design and implementation of the new curricula: (1) Integration of modern technologies; (2) Sustaining a student-centered education with multiple hands-on experiences; and (3) Initiation of an outreach program to expose youth to design and manufacturing. Below is the implementation details measured against the objectives.

(1) <u>Integration of modern technologies</u>

Modern technologies have been well implemented across seven design and manufacturing related courses. Computer-aided modeling and manufacturing techniques were reviewed in MECH 310 and further discussed in MECH 476 for product prototyping and realization. Cutting-edge technologies for product design analysis were introduced in MECH485. The integration of modern computational technologies allows our students to develop practical skills and experience in commercial CAD/CAE/CAM packages that are extensively used in today's product development environment.

Rapid prototyping (RP) is an advanced layer-manufacturing technology that can quickly generate complex 3-D objects directly from computer-based models devised by CAD. In Mech476, a series of RP projects are integrated. Students designed complex geometries and build their parts using the RP systems. The students also conducted manufacturing experiments to analyze the processes and products quality in MECH 310. Through new manufacturing laboratories in the course, the students could run various modern manufacturing tools such as CNC machines, machining force monitoring systems, and product quality measurement systems. See Figure 2 for some sample student work using the modern technologies.



(a) CAD design (b) CAE analysis (c) Rapid prototype

Figure 2. Student work examples in the Design/Manufacturing sequence.

Lean manufacturing, the processes that eliminate all possible "wastes" or "non-value-added" activities in manufacturing, was integrated into MECH476. Students conducted lean manufacturing practices to determine the major causes that create "waste" in factories, and how to minimize or eliminate them. Advanced materials including non-ferrous metallic, polymer, and composite materials have been integrated into various courses in the sequence. Nanomaterials and other advanced materials systems were instructed in MECH309. In MECH476, students learned material processing technologies for non-ferrous metallic, polymer, and composite materials.

(2) Emphasis on student-centered education with multiple hands-on activities

The design and manufacturing sequence have incorporated extensive hands-on lab activities. The labs provided students with the opportunity to integrate and apply their knowledge to real engineering problems.

MECH 476 offered three activities related to RP, plastic processing, and lean manufacturing. Students designed and built their own products using the RP systems. Open plastic molding was used to mass-produce their RP parts. Through this mass production environment, they applied lean manufacturing principles into their production line to identify “non-value-added” activities or “waste” and minimize them. In MECH485, stress, vibration, thermal, fatigue, optimization, buckling analysis labs were introduced to gradually develop students’ problem-solving skills in CAE. Students learned how to obtain various structural and thermal solutions, based on which they can determine, e.g., whether a product design is good and safe for its intended use.

(3) Outreach to expose youth to the design and manufacturing

Two outreach workshops were conducted to expose youth to design and manufacturing. They were Southwest Washington Math Engineering Science Achievement (MESA) Summer Camp 2007 (July 16 – July 20, 2007) and Saturday Academy Winter 2008 Class (Feb. 23 – March 15, 2008). Total of 23 junior-high students attended both workshops. During the workshops, the students used computer aided design (CAD) software and rapid prototyping (RP) tools to design and manufacture their own picture frames. Students also conducted experiments on casting, plastic molding, and material property testing at the state-of-art engineering laboratories at WSU Vancouver. At the end of the workshop, students were asked to complete a survey regarding their impressions of the activities and suggestions for learning. Overall, students felt they were very excited by the workshop activities. They liked the CAD modeling activity the most. They reported that the workshop very effective in helping them improve their understanding of engineering. Even though they are quite young to think of their careers, more than 50% of the students said that Mechanical/Manufacturing Engineering could be a probable career in the future.

4. Design and Manufacturing Track Evaluation

The design and manufacturing track first offered in the academic year of 2004-2005. In order to monitor the students’ satisfaction on the design and manufacturing track, three evaluation methods were used: 1) student enrollment data, 2) senior exit survey, and 3) focus group meeting. Figure 3 shows the student enrollment for three tracks from 04-05 to 06-07. Table 2 shows the number of graduates who completed each track area. Note that a few students completed more than one track area.

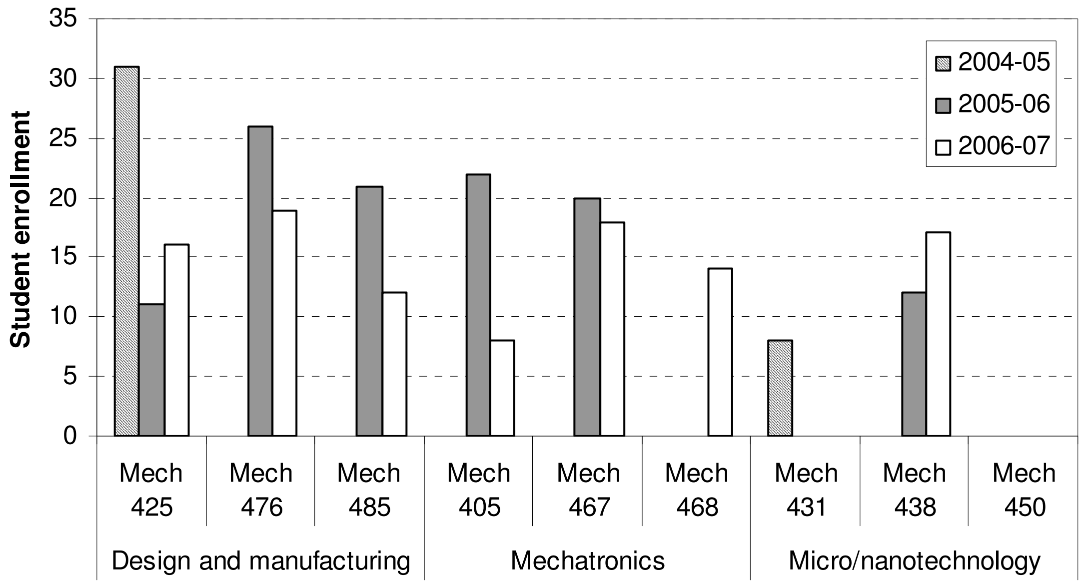


Figure 3. Student enrollment for three tracks from 04-05 to 06-07.

Table 2. Number of graduates completed each track

	Total number of graduates	Design and Manufacturing	Mechatronics	Micro/Nanotechnology
06-07	28	11	14	0
07-08	23	16	8	0
08-09	34	15	9	9

The evaluation of teaching can be an appropriate measure on how well the course has been instructed to the students. From 04-05 to 06-07, average evaluation scores of the design and manufacturing track courses range from 3.64 to 4.66 out of 5. The track's average score was 4.3 while the college average is close to 4.1. Student feedbacks on the course evaluation were also very positive. Many have indicated that they thoroughly enjoy the classes, especially the many hands-on lab sessions.

According to the senior exit survey results, many graduating senior students have indicated that the track courses are very hands-on and informative. Some mentioned that learning these newly integrated tools had already helped them dramatically at work. Most of the students recommended others to take the design and manufacturing track.

5. Summary and Future Improvement

American industry has awakened to the importance of the manufacturing enterprise and the need for design and manufacturing education. In order to fulfill a shared nationwide vision and a wholehearted support from our students and the local industry, the mechanical engineering program at Washington State University Vancouver offers a track area of Design and

Manufacturing. The track sequence courses (Introduction to Manufacturing Systems, Advanced Manufacturing Engineering, and Computer Aided Engineering) have been designed to provide students multiple hands-on experiences in modernized computer integrated tools and advanced materials and manufacturing systems. Student feedbacks in the track courses were very positive and teaching evaluation scores were higher than the college average. Among three track areas offered in the program, the largest number of students has completed the design and manufacturing track.

For future improvement of the design and manufacturing track, we plan to emphasize more on contemporary design issues such as design failures due to fatigue and wear, modern product design using energy efficient and other advanced material systems, design for manufacturability and assembly (DFMA) and its product life cycle impacts.

Acknowledgements:

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