2006-130: CURRICULUM DEVELOPMENT FOR AN INTERDISCIPLINARY MANUFACTURING ENGINEERING PROGRAM

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Curriculum Development for an Interdisciplinary Manufacturing Engineering Program

Abstract

This paper outlines the curriculum development effort for improving the interdisciplinary engineering program at the University of Missouri-Rolla (UMR). UMR currently offers two BS degree option programs in manufacturing, one in Mechanical Engineering and the other in Engineering Management, and MS degree programs in manufacturing are also offered. As the manufacturing engineering program is relatively expensive to run, especially the manufacturing laboratories, a strategy to integrate various campus resources in materials and processes on campus to improve the curriculum has been implemented. The collaborations with manufacturing companies and other partnering institutions to enhance the program are discussed. Also included in this paper are the major curriculum development and outreach activities, including an interdisciplinary capstone design project to provide opportunities for students to design, manufacture, and actually market a product, which can stimulate students' interest in real-world product realization, the summer manufacturing workshop for high-school teachers and students, and research programs to develop laboratory facilities and support graduate programs.

Introduction

To live well, a nation must produce well. U.S. manufacturing is a critical area that cannot afford to be lost, but it is facing a great challenge. When the industry's manufacturing jobs are out-sourced, engineering and design jobs will follow, as an engineer cannot design a product well without knowing how to manufacture a product. Although outsourcing could be just a part of globalization, it may permanently hurt the U.S. industry's competitiveness and product innovation capability if the trend continues. In order for the U.S. to stay competitive, product innovation is the best strategy so that consumers will continue to purchase higher priced yet higher value products. It is critical to educate our future engineers about the importance of manufacturing[1].

To respond to the need for the enhancement of manufacturing education, the Coordinating Board for Higher Education in cooperation with the Missouri State Board of Education prepared a Missouri State Plan for Post-Secondary Technical Education, and this has culminated in UMR's mission to establish new programs in manufacturing. As a result, the UMR Manufacturing Engineering program was initiated in year 2000. It offers interdisciplinary Master of Science and Master of Engineering degrees in Manufacturing Engineering, BS Mechanical Engineering with Manufacturing Option, and BS Engineering Management with Manufacturing Option.

This paper summarizes the challenges, program structure, resources seeking efforts, and major curriculum development activities of this interdisciplinary manufacturing engineering program.

Program Structure

The program was initiated based on the concept of using the existing resources to accomplish the mission, and thus has been a very challenging task in terms of resources. This is especially problematical for a manufacturing program as it requires costly manufacturing facilities for a quality curriculum. As the manufacturing engineering discipline includes materials, processes, and management, it is a logical step to set up an interdisciplinary program structure. However, as it is different from the traditional academic departments, the challenge is program coordination. The program currently has 40 faculty members from around the campus, including faculty from Basic Engineering, Ceramic Engineering, Chemical Engineering, Computer Science, Electrical and Computer Engineering, Engineering Management, Mechanical Engineering, Metallurgical Engineering, and Mining Engineering, with most involvement from Mechanical Engineering, Engineering Management, and Metallurgical Engineering departments.

The interdisciplinary Manufacturing Program is coordinated by the Manufacturing Education Executive Committee (MEEC) including five faculty representatives: Coordinator of *BS Manufacturing Option in Engineering Management*, Coordinator of *BS Manufacturing Option in Mechanical Engineering*, a Representative from the *School of Materials, Energy & Earth Resources*, an endowed Professor in the Manufacturing area, and the Director of the *Manufacturing Engineering Program*. This committee is chaired by the Director of the Manufacturing Program, and is administered through the Dean's office.

This interdisciplinary committee structure has proven to be very effective in implementing such an interdepartmental program. All the manufacturing related courses are associated with the individual departments and are assigned to the associated department's course title. In other words, no "manufacturing" course is offered. On the countrary, the manufacturing program has helped faculty in various departments develop manufacturing related courses. The objective of our program is not only to enhance the manufacturing discipline, but also help the other departments grow. This is the way the collaborations grow in the long term. As part of the UMR manufacturing startup program, 13 internally funded curriculum development projects, at a total of $200,000, have been selected to enhance and develop our manufacturing education. The development activities can be summarized below:

1) Manufacturing process and manufacturing materials courses and laboratories: Composite Manufacturing; Transport Phenomena in Manufacturing Processes; Materials for Manufacturing; and Computer Numerical Control of Manufacturing.
2) Product and Assembly Engineering: Sustained Product Design and Reverse Engineering; Assembly Engineering; Mechatronics & Assembly; Rapid prototyping/tooling; and Human Factors and Ergonomics; Concurrent Engineering.
3) Manufacturing Systems: Automation in Manufacturing
4) Other Special Laboratory Development: Distance Laboratory Experiment.

In addition, the Industrial Advisory Board (IAB) has also been formed to help define this program with the objective of being responsive to industry needs. These companies include:

- The Boeing Company in St. Louis, Missouri;
- Briggs & Stratton, Rolla, Missouri;
- Caterpillar Inc., Peoria, Illinois;
- General Motors, Inc., Lansing, Michigan;
- GKN Aerospace, St. Louis, Missouri;
- Honeywell, Kansas City, Missouri;
- Missouri Enterprise, Rolla, Missouri;
- Olin Corp., St. Louis, Missouri;
- SME St. Louis Chapter 17; and
- Quest Manufacturing, Inc., Strafford, Missouri.

The IAB members are managers that have volunteered to work with the program to develop this curriculum. In addition to the frequent communication through e-mails and phone contact, members attend annual meetings and provide guidance in curriculum improvement.

Resources for Program Maintenance:

Since manufacturing facilities are very capital intensive and require constant maintenance, it is a major challenge to maintain all the facilities for student use. Many of the experiences of the product realization process concurrently gained by students are severely limited by the types of manufacturing processes available at their universities. Also, it is unrealistic to expect that every institution will be equipped to handle a broad range of "real-life" products used for product realization projects. This interdisciplinary executive committee setup for faculty from various backgrounds can effectively allow the students in the program to access existing manufacturing facilities, including:

- Integrated Systems Facility (Engineering Management);
- Agile Manufacturing & Automated Inspection Lab (Mechanical Engineering);
- Virtual & Rapid Prototyping Lab (Mechanical Engineering);
- Augmented Reality Lab (Mechanical Engineering);
- Sustainable Design Lab (Engineering Management);
- High Pressure Waterjet Lab (Mining Engineering);
- Laser Welding Lab (Mechanical Engineering);
- CNC Lab (Engineering Management);
- Composite Manufacturing Lab (Mechanical Engineering);
- Computer Vision (Electrical and Computer Engineering);
- Lab for Industrial Automation & Flexible Machining (Mechanical Engineering);
- Automated PC Board Milling Machine (Electrical and Computer Engineering);
- Foundry for Ferrous and Non-ferrous Alloys (Metallurgical Engineering);
- Intelligent Control of Machining Lab (Mechanical Engineering);
- Digital Image & Signal Processing Lab (Electrical and Computer Engineering);

- Laser Aided Manufacturing Processes Lab (Mechanical Engineering).

Figure 1 shows the related laboratories on campus which are used by the manufacturing program. This coordinated effort greatly enhances the strength of the program. As the associated courses belong to different departments, all departments are happy with such an arrangement since more students are taking their courses. This is a win-win arrangement, because the students in the program can freely access the excellent curriculum and laboratories on campus. As there are many courses and laboratories available, it helps resolve some potential issues such as scheduling of classes for students.

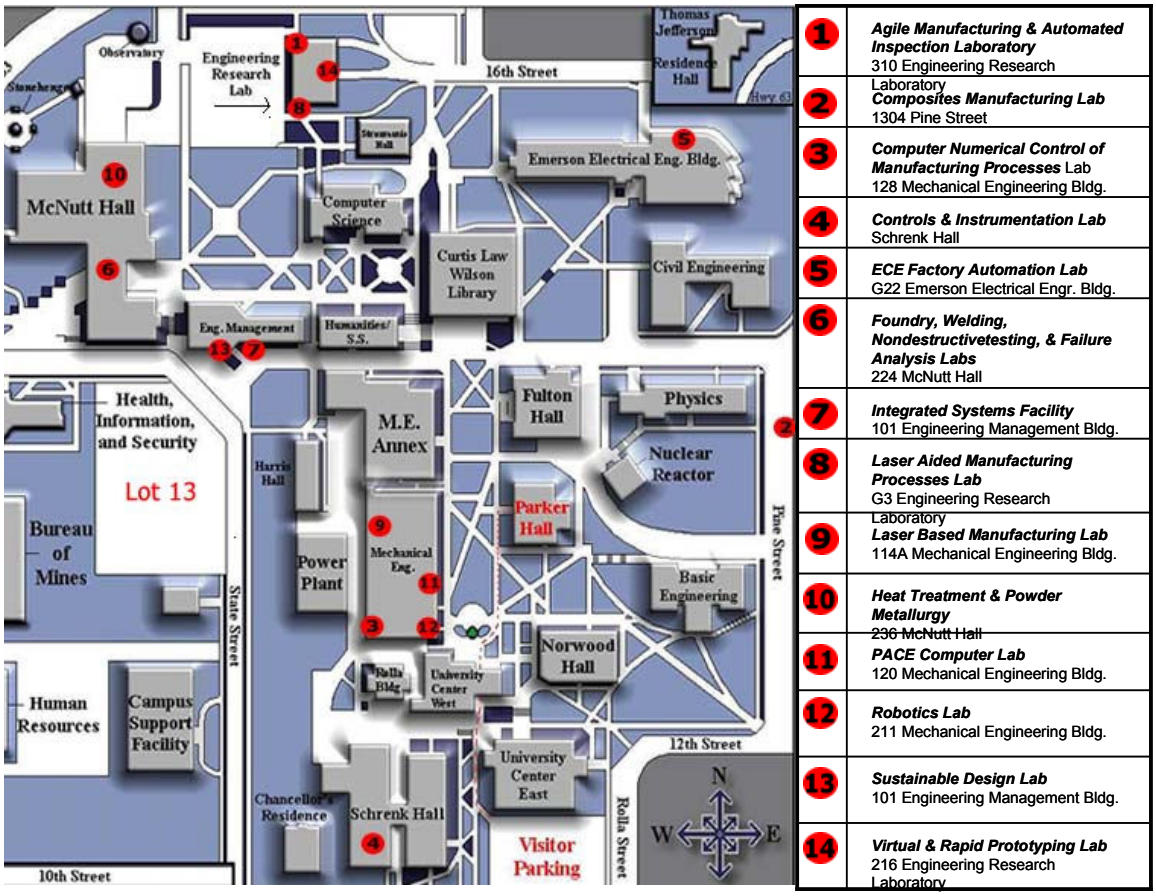

Figure 1. Distribution of Manufacturing Laboratories at UMR campus

The interdisciplinary program structure and Industrial Advisory Board certainly increase the visibility of the program, which helps attract a lot of internal and external support. In October 2000, through a grant provided by the PACE (Partners for the Advancement of CAD/CAM/CAE Education) program, General Motors Corp., Unigraphics Solutions, Sun Microsystems, and Electronic Data Systems donated 45 state-of-the-art computer workstations and solid modeling software to UMR's design and manufacturing program. GM also contributed $20,000 in cash to support the proposed program. Ford Motor Company donated $250,000 in cash toward establishing a virtual reality laboratory for design and manufacturing activities at UMR, and Boeing contributed $645,000 to support

UMR's Product Innovation Center. In addition, Boeing, Briggs & Stratton, Caterpillar, and Partner Precision have also expressed full support of the program in the form of evaluating our program, providing co-op and senior design projects, and engineer support. Some of the sponsored projects from SME (Society of Manufacturing Engineers) and NSF ATE (Advanced Technology Education) have greatly enriched the program activities. The new Center for Aerospace Manufacturing Technologies (CAMT) with over $11M in funded projects certainly boosted the research and education activities for the program Some activities are summarized below.

Program Implementation: Capstone Courses:

In order to take advantage of the interdisciplinary program structure, an interdisciplinary capstone design project course was created with the support of distributed and integrated manufacturing processes. Funded by SME (Society of Manufacturing Engineers), this project course provides students with the experience of integrating the technical knowledge they have learned from other courses. The project highlights include 1) Integration of business and engineering skills through a two-semester, team-based capstone manufacturing project course; 2) Development of a distributed product design and manufacturing environment including a realistic supply-chain network; 3) Development of modular courseware to support the capstone design project; 4) In-depth understanding of product quality and manufacturing process control; 5) Implication of various decisions such as make/buy, purchase, vendor selection on the bottom line; and 6) Real world industrial projects supported by various industrial partners.

The two-course sequence enables the students to learn about the following subjects:

1. Acquisition of customer's requirements;
2. Problem formulation;
3. Cost estimation;
4. Product conceptual design;
5. Product representation (Solid Modeling);
6. Product conceptual prototyping;
7. Make/buy decision;
8. Manufacturing process capabilities;
9. Manufacturing process identification;
10. Process planning;
11. Fabrication and Assembly.

In this course, interdisciplinary teams with students from various engineering and technology disciplines worked together to design, manufacture, and assemble real-life products. UMR senior students in manufacturing options, students with minors in manufacturing participated in this course. Students in the UMR MS program actively participated in the project as part of their practice-oriented credit requirement. The project courses took advantage of the manufacturing options being offered in both the Mechanical Engineering and Engineering Management departments. It was intended to simulate the modern industrial product development and manufacturing process in which engineers from various disciplines work together, and each team member contributes

his/her expertise to accomplish the project. We invited students from various disciplines to enroll in this course. In the first year of the course offering, there were 30 students in the class, 14 with an Engineering Management major, 9 from Manufacturing Engineering, and 7 from Mechanical Engineering. Students in Mechanical Engineering have a solid background in product configuration/definition/analysis, process development, and some manufacturing processes, while students in Engineering Management have good knowledge in marketing/cost analysis, quality engineering, and project management, while students in Manufacturing Engineering are more familiar with manufacturing processes and hands-on fabrication experience. They actually worked in teams with various academic background to perform concurrent product design and manufacturing.

Their customer was the sponsoring company that was interested in prototyping a product, or in testing a new process. In case the produced product was a prototype, the students had to develop marketing and manufacturing plans for quantity production. Student teams made presentations each week to report their project progress. This way they learned from each other at various product development stages. We found that this also provided great motivation for each team to keep good pace with the other teams.

Several companies participated in our project course by sponsoring the capstone projects. They include:

- Wood Pro, Cabool, Missouri;
- Eyes of the World, Rolla, Missouri;
- Watlow Industries, St. Louis, Missouri;
- Meta Stable, St. Louis, Missouri;
- Design Optimization Technologies, St. Louis, Missouri;
- Prier Products, Grandview, Missouri;
- Missouri Enterprise, Rolla, Missouri.

The funded projects include Exercise Machine (Figures 2 and 3), The Wood Cabinet (Figure 4 right), Laser Lens Director (Figure 4 left and middle), Electric Heater, etc. These companies also invested their engineering time and other resources to the project. Students were given real-life projects based on manufacturing processes and were required to analyze unit steps and suggest possible innovations. Many industries have instituted worker incentive programs that seek suggestions for product and process improvement. We would like to introduce this concept in the classroom and train young minds to ‘think differently’ and plant the seeds for them to become future process innovators.

Figure 2. Product demonstration: fix the machine to the bed

Figure 3. Product demonstration: Do sit up on the bed

Figure 4. Some representative prototype products developed and fabricated by the students in the capstone design projects, including housing and part of the assembly for a lens directing device (left), the assembly of a low cost laser director (middle), and the wood furniture prototype (right).

Integration of Research and Education

Since one focus of the program is graduate study, research is an important element of the scholarly activities. With the support of Wright Patterson Air Force Research Laboratory and the Boeing Company, the Center for Aerospace Manufacturing Technologies (CAMT) was established in 2004 with funding of more than $11M for advanced manufacturing research. The mission of the Center for Aerospace Manufacturing Technologies is to serve as a center of excellence for research, development, evaluation and demonstration of new and optimal methodologies and tools for the rapid and cost-effective manufacture of aerospace components and products. CAMT will also promote new education and training programs for the evolving aerospace manufacturing workforce, resulting in significant technological advancement and national economic impact. The thrust areas include 1) Advanced Simulation, 2) High-Speed Machining, 3) Abrasive Slurry Cutting, 4) Rapid Prototyping and Manufacturing, 5) Laser Materials Processing, 6) Friction Stir Processing, 7) Non-Chrome Coating, 8) Non-Destructive Evaluation, 9) Composites Manufacturing, and 10) Electronic Materials Processing. This project involved over 30 faculty from various disciplines and roughly 50 graduate students, and thus had a great impact on the scholarly activities. Most of the faculty

members in the interdisciplinary manufacturing program are involved in the activities. Many new laboratories have been established as a result of this project, for example, Friction Stir Processing Facility, NDE and Structural Health Monitoring Laboratory, Ceramic Processing/Properties Laboratories, Micro-Machining Laboratory, Plasma Spray Facility etc. Although most of these laboratories are for research, they are being used as part of the laboratories for graduate level classes.

Outreach to High School Teachers and Students

One important outreach activity for the program is to inform high school teachers and students about the engineering profession, especially manufacturing engineering. It is a common misconception that the only jobs in the manufacturing industry are for machine operators. However, industry's needs are much broader. Manufacturing is more than machining. The personnel needed by this industry must be able to perform multiple functions from design to distribution. In other words, the manufacturing industry needs to be seen holistically – as a complete system involving many people of varying educational backgrounds. Companies are looking for individuals with diverse technical expertise to perform multiple functions in support of their manufacturing enterprises. Many youth and adults have little knowledge of engineering and manufacturing career options. Parents, teachers, and educators lack exposure to the understanding of the highly technical manufacturing world. Early education is the key element in engineering and manufacturing career awareness.

We taught advanced manufacturing technology to groups of teachers at a workshop sponsored by NSF during the summers of 2004 and 2005 at the University of Missouri-Rolla. Each year there were 25 to 30 teachers and students participated in the workshop. The purpose of the workshop was to expose teachers to manufacturing technology in the hope of impacting the career choices of their students. Some high school students also participated in the workshop. The material presented in the workshop included CAD modeling, rapid prototyping, and lean manufacturing. Some industrial representatives came to the workshop to interact with the teachers and students on the perspective of advanced manufacturing technologies. The participants also toured manufacturing research laboratories on campus and two local manufacturing facilities in the community.

Table 1, below, shows the schedule for the week-long workshop. The workshop began at 9.00AM each morning and introduced new technologies in manufacturing to its participants.

Mon. July 19	Activities
9 am	Introductions and orientation Frank Liou 214 MEAX
9:40	Manufacturing in Industry John Fargher, Missouri Enterprise and Linda Puzey, General Motors 214 MEAX (Break at 10:30 am)
12:00	Lunch Cafeteria
1:00	Solid Modeling Siddharth Shinde ME-217
2:30	Break
2:45	Solid Modeling ME-217
3:45	Wrap up day ME-217
4pm	Dismiss

Tue. July 20	Activities
9 am	Solid Modeling ME-217
10:30	Break
10:45	Solid Modeling ME-217
12:00	Lunch Cafeteria
1:00	RP: Todd Sparks, Vinay Kadekar, Yogesh Thakar ME-217
2:30	Break
2:45	Rapid Prototyping ME-217
3:45	Wrap up day ME-217
4pm	Dismiss

Wed. July 21	Activities
9 am	Rapid Prototyping ME-217
9:30	FDM, LAMP, Modeling ME-217 MEAX 120B G3 ERL
11:00	Prototype Review ME-217
11:30	Lunch Cafeteria
12:30	Car pool
1:00	Manufacturing Industry Tour: Brewer Science
2:30	Manufacturing Industry Tour: Briggs & Stratton
4pm	Dismiss

Thru July 22	Activities
9 am	Lean Manufacturing Venkat Allada Faisal Anam EMgt-104
10:30	Break
10:45	Lean Manufacturing EMgt-104
12:00	Lunch Cafeteria
1:00	Lean Manufacturing EMgt-104
2:30	Break
2:45	Lean Manufacturing EMgt-104
3:45	Wrap up day EMgt-104
4pm	Dismiss

Fri. July 23	Activities
9 am	Manufacturing Laboratories Overview MEAX 214
9:20	Campus Laboratory Tour: Composite Manufacturing Lab, ISF Lab, Rock Mechanics Research Center, Virtual Reality Lab
12:00	Lunch Cafeteria/
1:00	Research Opportunities Ming Leu MEAX 214
2:30	Break
2:45	Feedback and discussions MEAX 214
3:45	Wrap up MEAX 214
4pm	Dismiss

Table 1 – Workshop Schedule

The workshop contained lectures and activities on solid modeling, rapid prototyping, and lean manufacturing. Two industrial representatives also participated in the workshop and interacted with the participants on the perspective of manufacturing world.

The representative from Missouri Enterprise focused on manufacturing careers and activities in small/medium businesses, and the representative from General Motors talked about manufacturing from the standpoint of larger companies. The goal was to expose the teachers and students to the manufacturing profession from the viewpoint of these two industrial experts. To fit with the theme of the workshop, advanced manufacturing technologies were emphasized since CAD/CAM and lean manufacturing were discussed in the workshop. There was quite a bit of discussion and interaction regarding the world of manufacturing.

The Discover Manufacturing Workshops were very successful in disseminating information on manufacturing technology to teachers and students. The participating teachers intended to pass this information onto their future students. The campus laboratory tour was a topic of interest to both the teachers and students. This is not too surprising since the participants were able to observe state-of-the-art manufacturing research on campus. Faculty and student participation in the demonstration of various research projects to the teachers and students was also a factor to the success of the workshop.

Distance Education for Life Long Learning

In addition to the on-campus students, the program also offers a distance education program for working professionals. Due to the interdisciplinary nature of the program, the admission requirement for Master of Engineering is a BS in engineering. As many

engineers while working in the manufacturing industry have found themselves with a lack of adequate knowledge in the manufacturing area, there is a great need to offer the distance program for these students.

We have developed a Masters degree program in Manufacturing Engineering that is accessible through the Internet. Many people working in industry will be able to benefit from this program by participating through distance education and flexible scheduling. This program is the only master-degree program of its kind in Missouri and is among the first in the nation. The interdisciplinary manufacturing program provides two degree options - a Master of Science degree and a Master of Engineering degree, although many distance students have taken the Master of Engineering option. Both degree programs are offered in the traditional format as well as through the Internet, so that students can access the lectures anywhere at any time. Features of this program include:

- Fully web-based distance education for students working in industry. Students can enroll in this degree program to study either on-campus or off-campus.
- Interdisciplinary faculty expertise and facilities. More than 10 academic departments and research centers support this program.
- Working with manufacturing companies under co-op and internship arrangements.
- Completion of practice-oriented Master of Engineering Degree requirements in one year.

Courses are offered via the Internet. Students may attend class real-time via the Internet from home or place of employment. In most cases, there is a two way audio connection with the class to permit live interaction with other students and the professor. All classes are archived on the internet to provide access to recorded lectures at a later time if they are unable to attend or need to review the material at a later date.

The degrees require 30 credit hours of approved course work. Distance students get the same opportunities as on-campus students but with the convenience of the instruction coming to them. It's an "Education that Fits" their needs. Currently there are over ten graduate students in the distance education program, and many of them the tuitions were paid by their affiliated companies.

Conclusion:

In this competitive global market, U.S. manufacturing companies are facing severe challenges and the news media has reported that manufacturing jobs are being outsourced to other countries. As a result, there are doubts whether we should even educate engineers in this area, and many students were discouraged by the news. The fact is that the job outsourcing is just a normal trend of a global market and more Americans are employed now than ever before. The household employment survey of Americans indicates that there are 1.9 million more Americans employed since the recession ended in November 2001[2]. Most nations are losing manufacturing jobs worldwide, even China, and this is because of new technologies, such as automation and information technologies, which can make high quality and low cost products. The trend is that the direct labor requirement is dramatically decreased and engineers with high level skill are greatly

needed. In such an environment, in order to maintain a high quality manufacturing program and recruit high quality students, creativity in program structure and fund raising activities are critical to the success of the program.

The UMR manufacturing engineering program has set up an interdisciplinary program structure which has been proven to work. Currently there are over thirty undergraduate students in manufacturing options and over thirty graduate students in the master's program, and each year there were over ten graduate students graduated, most of them accepting a job offer before they graduated. Several graduate students received campus recognitions, such as the best graduate student in Engineering Management, best poster award in Intelligent Systems Center, and won several national awards or recognitions, such as the best poster in 2005 ASNT Conference, the best poster award in 2005 SFF Symposium, and the finalist for 2005 ASME manufacturing design competition. The effort of integrating the existing campus manufacturing resources and those available from industries to provide manufacturing experiences for students can be adapted at other institutions that have limited manufacturing process equipment facilities. The interdisciplinary team-based format for the capstone course is very different from the traditional senior design projects in which most students will have similar technical backgrounds. An interdisciplinary team will provide the students with the experience of solving a problem using various team members' expertise.

Bibliography

[1] SME (Society of Manufacturing Engineers), retrieved on Feb 14, 2006 from http://www.sme.org

[2] Tim Kane, Brett D. Schaefer, and Alison Acosta Fraser, "Ten Myths about Jobs and Outsourcing", retrieved on Dec. 8, 2005 from http://www.heritage.org/Research/TradeandForeignAid/wm467.cfm.

Acknowledgments

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