

AN INTEGRATED AND DISTRIBUTED ENVIRONMENT FOR A MANUFACTURING CAPSTONE COURSE

Frank Liou, Venkat Allada, Ming Leu, Rajiv Mishra, Anthony OKAFOR

**University of Missouri-Rolla
and**

**Ashok Agrawal
St. Louis Community College - Florissant Valley**

Abstract

Presented in the paper is an interdisciplinary capstone design project course with the support of distributed and integrated manufacturing processes. 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, purchasing, vendor selection on the bottom line; and 6) real world industrial projects supported by various industrial partners. Presented in the paper is the integration of the existing campus manufacturing resources and those available from industries to provide distributed manufacturing experiences for students. The collaboration between the University of Missouri-Rolla and St. Louis Community College at Florissant Valley integrates engineering and technology to solve real problems in industry. An interdisciplinary team provides the students with the experience of solving a problem using various team members' expertise. This capstone design project provides opportunities for students to design, manufacture, and actually market a product, are able to stimulate students' interest in real-world product realization. Business knowledge and skill are naturally incorporated into consideration in students' design and manufacturing. Both the program model and actual class implementation are summarized in this paper. This model can also be adapted at other institutions that have limited manufacturing process facilities.

I. Introduction

An innovative product-oriented manufacturing curriculum is being implemented at the University of Missouri-Rolla (UMR) and St. Louis Community College at Florissant Valley (FV)¹. This project has significantly impacted UMR's two BS degree option programs in manufacturing and MS degree programs in manufacturing, and FV's manufacturing engineering and technology programs. We have established an integrative and collaborative manufacturing program to reinforce and sharpen critical competencies

of students. The centerpiece and uniqueness of this program is a senior-level, two-semester capstone manufacturing project course that provides students with the experience of integrating business and engineering skills toward rapid, distributed product realization, and a 2-plus-2 articulation between an AS degree Manufacturing Engineering Technology program to a BS degree Manufacturing Engineering program. The term “distributed” is used to emphasize that the student team is expected to use facilities that are distributed at manufacturing laboratories on both campuses and facilities of outside vendors and suppliers. This project course also provides students with the experience of integrating the technical knowledge they have learned from other courses. The development effort for the courses and lessons learned are reported and summarized in this paper.

II. Capstone Project Courses

The two-semester capstone project courses have been developed and offered. The two-course sequence enables the students to learn in 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, and FV students in the associate degree program 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 take advantage of the manufacturing options being offered in both the Mechanical Engineering and Engineering Management departments. It is intended to simulate the modern industrial product development and manufacturing process in which engineers from various disciplines are working together, and each team member contributes his/her expertise to accomplish the project. We invited students from various discipline to enroll in this course. In the first year of the course offering, there were 30 students in the class, with 14 with Engineering Management major, 9 from Manufacturing Engineering, and 7 from Mechanical Engineering. Students in Mechanical Engineering have 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 hand-on

fabrication experience. They actually worked in teams with expertise to perform concurrent product design and manufacturing.

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

III. Integrated and Distributed Manufacturing Facilities

Since manufacturing facilities are very capital intensive and require constant maintenance, it is a major challenge to maintain all facilities for students to 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 curriculum development effort also integrated the existing campus manufacturing resources and those available from industries to provide distributed manufacturing experiences for students. The collaboration between UMR and FV integrates engineering and technology to solve real problems in industry. One unique feature of the capstone project is the distributed product realization that ties together product realization process and supply chain management.

We have experimented a distributed product realization model that can be replicable at other institutions. The word “distributed” means that the manufacturing capability that is available at the disposal of the student team is distributed at 1) the home institution, 2) catalog part suppliers and vendors available through the internet and/or catalogs, and 3) job-shop vendors and suppliers who accept designs from clients before quoting. This concept has been implanted through two mechanisms: 1) A web site has been developed to document the campus manufacturing resources at both UMR and FV sites. The information includes machine types, machine configurations and capabilities, etc. so that students are able to make a decision in process selection for their product, and 2) The UMR Manufacturing Engineering program provides necessary coordination and sometimes provides resources to ensure that the students can access the desired facilities.

Students have access to the internet, handbooks, and catalogs to procure parts. Furthermore, students also have access to a selected list of vendors/suppliers (with varied degrees of manufacturing process capability) who would supply quotes based on the design drawings supplied by the student team. Based on product complexity, the student team is provided with the approximate percentage of parts and part types that can be manufactured in-house at UMR, procure “off-the shelf” components from catalog vendors, or request bids for some of their component drawings with vendors and the FV campus. Through this scenario, we will be able to provide students with the experience and “know-how” of the tactical advice on developing effective logistics operations and

unique insight into the operating environment for sourcing and procurement. For example, students can produce a product by making parts in-house, working with a vendor to produce a plastic or composite component, or matching and integrating with an ordered motor through the catalog. The integration, management, and communication involved in the process are a meaningful experience for all the students and faculty participating in the project.

IV. Modular Courseware to Support the Capstone Course

We have adapted, developed, and implemented several modular courseware to support the two-semester capstone design course. Since the project oriented course teams are multidisciplinary, we realize that students from different disciplines will have different technical backgrounds. However, if they have to work effectively in a team, there needs to be some common level of knowledge, especially where the integration of student know-how occurs. We adapted, developed, and used modular courseware to enable the students to effectively communicate with each other and execute the project. The courseware are web-based and some video-based. We have looked at several projects that are aimed at reforming the undergraduate design and manufacturing engineering curriculum. The ones most relevant to the present proposal include the following. 1) The Product Realization Consortium funded by NSF/TRP²; 2) The Project on Integrating the Product Realization Process (PRP) into the Engineering Curriculum conducted by a team of industrial and academic experts organized by ASME International and supported by NSF³; 3) Undergraduate engineering education projects such as SYNTHESIS Coalition⁴ and SUCCEED (NCA&T)⁵ funded by NSF; 4) The Multimedia in Manufacturing Education project at Georgia Tech⁶; 5) The Best Manufacturing Practices (BMP) program sponsored by the Office of Naval Research⁷; 6) The Stanford Global Supply Chain Management Forum⁸; and 7) North Carolina Consortium for Logistics Education⁹ funded by NSF.

The course modules from the above-mentioned resources have been adapted and integrated with the developed modules to support the capstone project course. They are self-contained, with practical examples, and fully accessible to students through the web and video. The modules include: team-based product development, project management, supply chain management, Unigraphics, Pro-E, product marketing and cost analysis, rapid prototyping, measurement and gauging, product assembly, welding, metal forming, punching, etc.

Each capstone project team is required to document their project through a multimedia presentation and report. A library collecting these reports, to be maintained by UMR's MEEP, have been established and available for other students to learn about the project's history. Successful or not, each case represents a valuable experience to be shared with others.

V. Partnerships with Industries

The partnership with industry is a critical step to the success of our project. Industry involved in our project in two areas: direct project support and industrial advisory Board:

1) Direct Project Support:

In the first year, several companies participated in our project course by sponsoring the capstone projects. They include:

- WOOD PRO, Cabool, MO
- EYES OF THE WORLD, Rolla, MO
- WATLOW INDUSTRIES, St. Louis, MO
- META STABLE, St. Louis, MO
- DESIGN OPTIMIZATION TECHNOLOGIES, St. Louis, MO
- PRIER PRODUCTS Grandview, MO
- MISSOURI ENTERPRISE, Rolla, MO

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 to train young minds to ‘think differently’ and implant the seeds for them to become future process innovators.

2) Industrial Advisory Board:

At present there are several members in the Industrial Advisory Board for this project, including the Boeing Company in St. Louis, Missouri; Briggs & Stratton, Rolla, Missouri; Caterpillar Inc., Peoria, Illinois; General Motors, Inc. Lansing, Michigan; Honeywell, Kansas City, Missouri; Mid-America Manufacturing Technology Center (MAMTC), Rolla, Missouri; Olin Corp., St. Louis, Missouri; SME St. Louis Chapter 17; and Visteon Automotive Systems, Dearborn, Michigan. These members have expressed their strong support for the manufacturing engineering curriculum and their interest in working with us to develop this curriculum. In addition to the manpower and facilities, they also helped to assess the success of project.

Mid-America Manufacturing Technology Center (MAMTC) has offered a lot of helps in coordination between local industry and the class activities. Their engineers currently provide technical assistance to thousands of small and medium-size companies. Such relationships have proven to be great assets to this project since their engineers know when these companies need help. With their help in coordination, we have obtained a steady supply of industry-sponsored projects.

VI. Class Examples

The first round of the classes has been successfully offered. The end product of the first course is to deliver a concept prototype and the second course is an engineering prototype. For example, one of the projects was to develop an assistance device to aid persons with performing sit-ups in bed. The target market is the elderly, but will be designed to attract users from other age groups. As the result, the concept prototype for

the exercise machine is shown in Figure 1 while the engineering prototype is shown in Figure 2.

In the first semester, the students worked with the sponsoring company to identify *Market Needs*: “A simple ergonomic design, cheap to build and purchase while being safe to use,” and identify *Unique Qualities of Design*: “Most exercise machines are made for hard floors or they come with their own bench. Our design allows the customer to be more comfortable because it is made for the bed.”



Figure 1. Concept prototype for an exercise machine.



Figure 2. Engineering prototype for the exercise machine.

They did a market survey to find customer needs and pricing (mean: \$20-\$30), and summarized their findings to make a QFD matrix to transfer the customer’s needs into their design engineering requirements. They then used Unigraphics to model, design, and analyze their machine structures as shown in Figure 3. The final machine model consists of many primitives, such as block, cylinder, hole, and some advanced features like thread, spring, blending and extruding, etc.

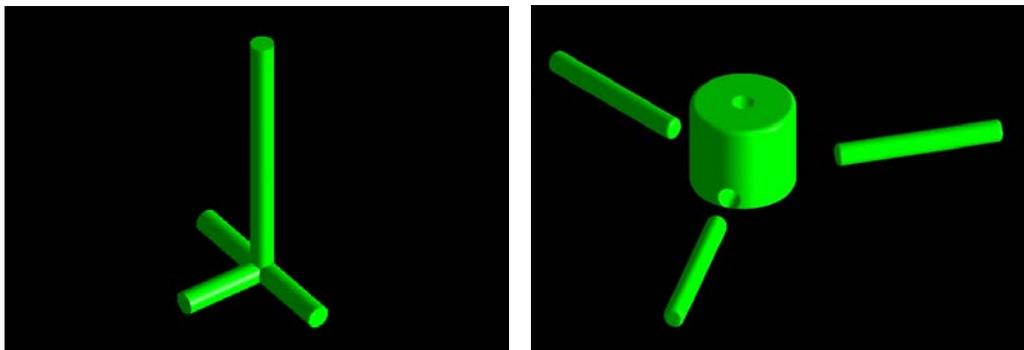


Figure 3. CAD models of the original base design (left) and final base structure (right) of the exercise machine.

The Manufacturing Processes involved in this project include the followings. The pictures were taken by the students in their development process.

- 1) Rapid prototyping to produce prototype parts
- 2) Cutting: to cut the aluminum pipe to make the legs and main body.
- 3) Facing and Turning: to do lathing for base dimension
- 4) Drilling: to drill holes for mail body
- 5) Tapping: to create the threads for the base
- 6) Machine: to create desired part shapes
- 7) TIG Welding: to join tube to the base



Figure 4. Some processes used in the capstone project: FDM Rapid prototyping machine (left), Cutting (middle), and Machining (right).



Figure 5. More processes used in the capstone project: Drilling (left), Tapping (middle), and Welding (right).

The total material cost for produce the engineering prototype was \$86.69, not including the cost of labor or facilities. Figures 6 and 7 show the product demonstration. Figure 8 shows some of the other products designed and fabricated by the students.



Figure 6. Product demonstration: fix the machine to the bed



Figure 7. Product demonstration: Do sit up on the bed



Figure 8. 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).

VII. Conclusion

This capstone project courses have been implemented and offered for one year, and the feedback and results are pretty encouraging. Based on the experience so far, we found that the major challenges were project timing and facilities. The students were greatly benefited from the weekly project presentations by each group. This is not only force them to keep pace with the other group in project schedule, but also learn from each other on how to proceed with each steps. According to the students' feedback, the fact that they can simultaneously observe the other seven projects on how the other groups defined their project, formulate the problem, design the product, order the off-the-shelf components, fabricate the parts, and put them together, is a great learning process.

Timing is critical due to the facts that all projects were industrial sponsored, and thus this put pleasure on both the students as well as the instructor. However this also created the real industrial environment and constraints into the classroom. Some factors critical to making the project smoother in terms of timing include the time needed to define the

project as well as the time required for material purchasing. The help from the industrial sponsors to provide necessary and timely support to define project scope at the beginning of the project is critical to the success of the project. The students also need to be aware of the schedule to order off-the-shelf parts. “Next day service” may not happen since some products could be not in stock, and may need to wait for several weeks before shipping. For the next year, we plan to move the project due date one week earlier than that of this year. This allows students to do extra finish work (with penalty) in the last week to improve the quality of the deliverables to industry. This also allows students to discuss and evaluate each other on how they can do better the next time.

With the coordination of our Manufacturing Engineering program, the students can access almost all the facilities. However, some of the facilities require excessive training before they can operate the machine. For example, a CNC mill machine operation may require not only machining and CNC programming experience, but often also requires CAD modeling of the parts. Therefore, careful coordination and planning of team members with the appropriate background are important when forming the team.

VIII. Acknowledgements

This project is supported by the Society of Manufacturing Engineers Education, Foundation Grant Number 010291. The support from The Boeing Company, Briggs & Stratton, Caterpillar, GM, Honeywell, Ford, Lemay Center, Mid-America Manufacturing Technology Center, Olin Corp, SME St. Louis Chapter 17; UGS, the state of Missouri, and Visteon Automotive Systems, Wood Pro, Eyes of the World, Watlow Industries, Meta Stable, Design Optimization Technologies, Prier Products, and Missouri Enterprise, is also appreciated.

IX. Bibliography

1. Liou, Frank, Venkat Allada, Ming Leu, Rajiv Mishra, and Tony Okafor, and , Ashok Agrawal, “A Product Focused Manufacturing Curriculum, 2002 ASEE Annual Conference & Exposition, Montréal, Quebec, Canada, June 16-19, 2002.
2. NCAT, “Product Realization Consortium,” retrieved Feb 12, 2003, from <http://www.ncat.edu/~ieen/>
3. Prziembel, C. E.G., 1996, “Integrating the Product Realization Process (PRP) into the Engineering Curriculum,” retrieved Feb 12, 2003, from <http://www.eas.asu.edu/~asufc/asmep/asmep.html>
4. Aldrich, Jeff, “The Synthesis Coalition” retrieved Feb 12, 2003, from <http://www.synthesis.org/>
5. Huynh Minh-Chau, 1998, “Technology-Based Curriculum Delivery,” retrieved Feb 12, 2003, from <http://www.visc.ece.vt.edu/succeed>
6. Mcklin, Tom, 1998, “MIME (Multimedia in Manufacturing Education),” retrieved Feb 12, 2003, from <http://mime1.gtri.gatech.edu/mime/>
7. ONR, April 2, 2002, “Best Manufacturing Practices (BMP) ,” retrieved Feb 12, 2003, from <http://www.bmpcoe.org/about/index.html>

8. Alison, Rountree, January 7, 2002, "Stanford Global Supply Chain Management Forum," retrieved Feb 12, 2003, from <http://www.stanford.edu/group/scforum/>
9. Kenan Institute, "North Carolina Consortium For Logistics Education – NCCLE," Retrieved Feb 12, 2003, from <http://www.kenaninstitute.unc.edu/centers/clds/nccle/nccle.html>

BIOGRAPHICAL SKETCHES

FRANK LIOU

Frank Liou is a Professor of *Mechanical Engineering Department at the University of Missouri-Rolla (UMR)*. He currently serves as the Director of the *Manufacturing Engineering Education Program (MEEP)* at UMR. His teaching and research interests include CAD/CAM, rapid prototyping, rapid manufacturing, and augmented reality. He has published over 80 technical papers, and has research grants and contracts over \$4M.

ASHOK. K. AGRAWAL, P.E.

Ashok. K. Agrawal is Chairman and Professor, *Engineering and Technology Department, St. Louis Community College*.. Recently completed one-year term as a Program Director, *Advance Technology Education (ATE)*, Division of Undergraduate Education, National Science Foundation. His primary responsibilities included management of the ATE and engineering projects, and interaction with college and university faculty from across the country.

VENKAT ALLADA

Venkat Allada is an Associate Professor in *the Engineering Management Department at UMR*. He is the director of the NSF and Halliburton Foundation funded *Sustainable Design Laboratory* at UMR, and serves on the editorial board of the *International Journal of Industrial Engineering*. His teaching and research interests include Rapid Product Realization, and green design and manufacturing. He has published over 50 technical articles and has received over \$2M in research grants.

MING. C. LEU

Ming C. Leu is the Keith and Pat Bailey Professor in Integrated Product Development and Manufacturing, in the *Department of Mechanical Engineering, UMR*. His research is in the areas of automated motion verification and planning, dynamics and control of robots, automated assembly planning, and layered manufacturing. He is the ASME Vice President-Manufacturing, 99-02. He has published various papers, and has research grants and contracts over \$2M

RAJIV. S. MISHRA

Rajiv Mishra is a full time Assistant Professor of *Metallurgical Engineering Department* at UMR. He currently serves as coordinator for the *School of Mines and Metallurgy* in the *Manufacturing Engineering Education Executive Committee (MEEEC)* at UMR. He is a Research Investigator at the *Intelligent Systems Center* and the *Materials Research Center* at UMR.

ANTHONY. C. OKAFOR

Anthony C. Okafor is an Associate Professor of *Mechanical Engineering at UMR*. He currently serves as the Coordinator of the *BSME-Manufacturing Option Program* in *Mechanical Engineering* at UMR. He is a Research Investigator at the *Intelligent Systems Center* at UMR. His teaching and research interests are Manufacturing Processes. He has published over 45 technical papers, has research grants over \$2M.