A PRODUCT FOCUSSED MANUFACTURING CURRICULUM

Frank Liou, Venkat Allada, Ming Leu, Rajiv Mishra, Anthony Okafor
University of Missouri-Rolla
and
Ashok Agrawal
St. Louis Community College - Florissant Valley

I. Abstract

The objective of this paper is to present an innovative product-oriented manufacturing curriculum and enhance manufacturing degree programs at the University of Missouri-Rolla (UMR) and St. Louis Community College at Florissant Valley (FV). This project will significantly impact UMR's two BS degree option programs in manufacturing and MS degree programs in manufacturing, and FV's manufacturing engineering and technology programs. We will establish an integrative and collaborative manufacturing program to reinforce and sharpen critical competencies of students. The centerpiece and uniqueness of this program will be a senior-level, two-semester capstone manufacturing project course that will provide 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 the UMR campus, FV campus, and facilities of outside vendors and suppliers. This project course will also provide students with the experience of integrating the technical knowledge they have learned from various other courses. The project highlights include:

- Integration of business and engineering skills[5] through a two-semester, team-based capstone manufacturing project course,
- Development of a distributed product design and manufacturing environment including a realistic supply-chain network,
- Development of modular courseware to support the capstone design project,
- In-depth understanding of product quality and manufacturing process control,
- Implication of various decisions such as make/buy, purchasing, vendor selection on the bottom line, and
- Development of an enhanced 2-plus-2 program between UMR and FV. Students in engineering and technology will be working together on joint industrial projects[6] and faculty will be encouraged to exchange activities such as conducting seminars and manufacturing workshops.

II. Background

The present era of customer-driven global competition, a consequence of lowering the barriers to the movement of goods, services and technology across the world in the last decade, has profoundly transformed U.S. industry. Although this transformation has not been uniform across all industry sectors, this new regime has imposed a culture of continuous change on corporations that need to remain globally competitive. Such corporations have to identify their core competencies and strive to be "world-class." The new paradigm of continuous change and the global imperatives for flexibility and agility have generated a need for engineering graduates who can migrate from one discipline to another, who are sensitive to non-technical issues, and are prepared for lifelong learning, and whose job functions may change many times over their career. The demand for such flexible and "evolvable" engineering graduates poses major challenges for the nation's engineering schools.

At present a significant discrepancy exists between the skills taught in universities and those needed by U.S. industry to succeed in the era of global competition. The major part of the problem rests with American engineering schools because they have not been directly exposed to the rigors of global competition. Arguably, in terms of their core competencies (delivery of undergraduate and graduate education, research, and development) U.S. engineering schools remain first-class in any global competition. However, engineering schools need to take more serious steps for change in order to perform more effectively their functions as suppliers of well educated personnel with the attributes desired by world-class corporations. The problem of the deficiencies between skills taught and those needed in industry has already been identified by various national organizations and agencies who are advocating a variety of reforms and enhancements in engineering education.[1, 2, 4, 5, 6, 9, 10, 11, 18]

The Society of Manufacturing Engineers recently conducted a workshop for industrial and academic leaders to review and identify the critical competency gaps for improved training of the future-manufacturing workforce. Among which *business knowledge/skills*, *international perspective*, *project management*, *communication*, *problem solving*, and *teamwork* were identified as professional competency gaps. *Supply chain management*, *specific manufacturing processes*, *manufacturing process control*, *manufacturing systems*, *quality*, *materials*, *product/process design*, and *engineering fundamentals* were identified as technical competency gaps. We at UMR and FV, along with the support of industrial partners and the State of Missouri, are working to develop our manufacturing curricula to close these gaps.

III. Proposed Approach

The proposed program is developed around a capstone design and manufacturing project course and the development of the program includes the following tasks:

- Developing a two-semester long, capstone design and manufacturing course for senior students: This course will be developed and coordinated by the UMR Manufacturing Engineering Education Program (MEEP). In this course, interdisciplinary teams with students from various engineering and technology disciplines will cooperate to design, manufacture, and assemble a real-life product. Their customer will be a sponsoring company that is interested in prototyping a product or process, or in testing a new product or process. In case the produced product is a prototype, the student team will have to develop marketing and manufacturing plans for quantity production.

- Integrating Distributed Manufacturing Facilities: To facilitate the above mentioned capstone design and manufacturing course, existing campus resources will be integrated so that students can produce a product using multiple manufacturing processes. Various campus manufacturing process laboratories, including casting, welding, machining, forming, molding, rapid prototyping/rapid tooling, and electronic fabrication will be organized and coordinated. These labs will be coordinated so that laboratory assistants will be trained and scheduled and students working on capstone projects can receive help from these assistants.
- Modular Courseware to Support the Capstone Course: We will develop modular courseware to support the capstone design course.
- Active Mechanism for UMR/FV-Industry Partnerships: We will continuously work with industrial partners to solicit real world case studies for the capstone course. Our students will be recruited by the partner companies to gain co-op experience. This experience is likely to lead to a capstone design and manufacturing project with the sponsoring company.

IV. Interdisciplinary team-based capstone project course

The proposed two-semester capstone project course is a truly interdisciplinary team-based course at UMR. UMR senior students in manufacturing options, students with minors in manufacturing, and FV students in the associate degree program will participate in this course. Students in the UMR MS program will actively participate in the project as part of their practice-oriented credit requirement. This capstone project course will 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. Students from various disciplines will enroll in this course. For example, as shown in Figure 1, students in Mechanical Engineering will have a background in product configuration/definition/ analysis, process development, and some manufacturing processes, while students in Engineering Management will have knowledge in marketing/cost analysis, quality engineering, and project management. They will be working in teams with expertise to perform concurrent product design and manufacturing.

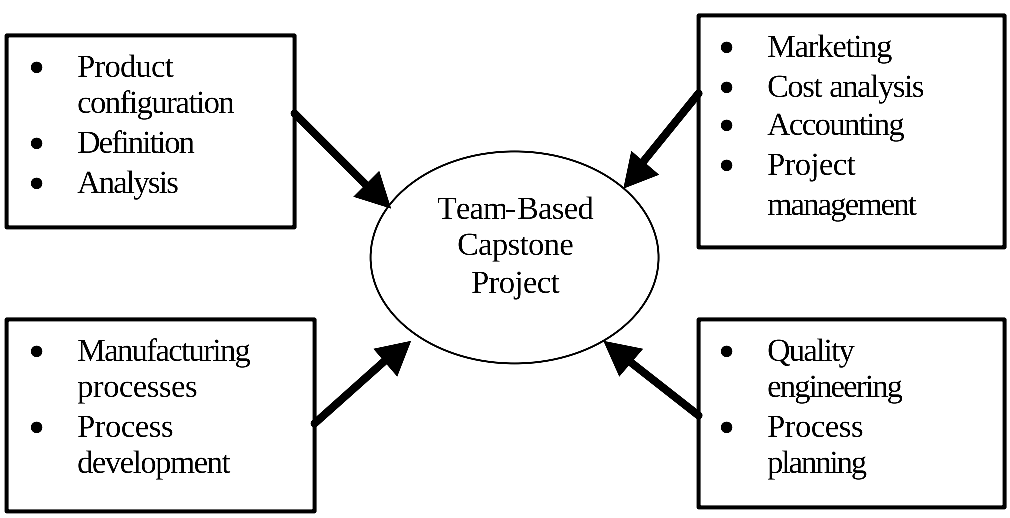

Figure 1. Disciplines of Students in the Team-Based Capstone Projects

The students in each group will be led by an instructor in manufacturing. Common web-based training modules will be provided in each capstone course to provide the students with sufficient basis to work as an integrated product development team. Although most of these courses are available as elective courses, common web-based modules will be developed and made available to students.

V. INTEGRATED AND DISTRIBUTED PRODUCT REALIZATION

One unique feature of the capstone project is the distributed product realization that ties together product realization process and supply chain management. 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. Faced with this dilemma, we have addressed the problem of limited manufacturing capability of any educational institution by adding the supply-chain dimension. In other words, we are proposing 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. The distributed product realization model is described further in the next section.

Distributed Product Realization Model

The distributed product realization model that will be employed is depicted in Figure 2. The students will be able to use the various manufacturing facilities at UMR and FV. Additionally, the students will have access to the composite manufacturing facility at Lemay Center in St. Louis. Students will have access to the Internet, handbooks, and catalogs to procure parts. Furthermore, students will 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.

Scenarios

Based on product complexity, the student team will be 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. Based on this information, the student team will be responsible for developing an efficient and cost-effective supply-chain framework for their product. 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 will be a meaningful experience for all the students and faculty participating in the project.

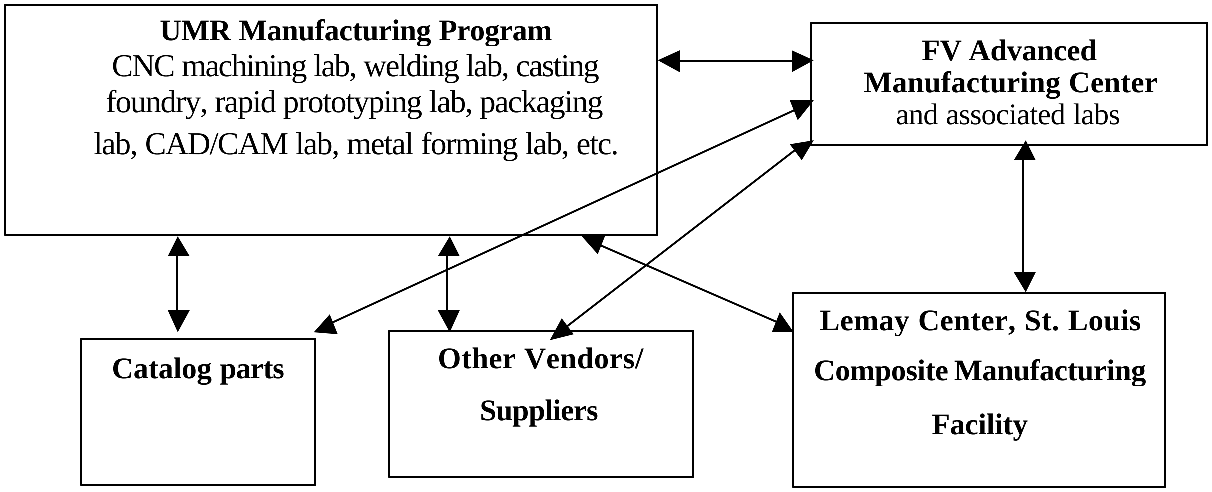

Figure 2. Distributed Product Realization Model

VI. Manufacturing curriculum and laboratory Development

The proposed real-life capstone project will significantly impact our existing manufacturing curriculum. One direct impact is on the inadequate process capability and quality of some existing manufacturing laboratories. Thus, further enhancement of these key laboratories is necessary.

One issue to be addressed is related to the nature of the interdisciplinary team. In this interdisciplinary team effort, a student team will work like a real-life team in industry with various combinations of team members, and each member's background can be different. For example, we found that each team with students from the manufacturing option programs in Mechanical Engineering and Engineering Management can sufficiently cover the backgrounds described in Figure 1. Therefore, the team will be able to function effectively. However, we believe it will be beneficial and effective to let each member learn some common basic knowledge so that the students do not need to learn about a team project starting from scratch. We propose to use multi-media modular courseware to enable the students to learn this common knowledge. It will be web-based and/or video-based so that students with different backgrounds can learn the material at their own pace. Therefore, the objectives of the course and laboratory development effort include:

- Enhancing manufacturing process courses and laboratories related to the proposed capstone projects
- Developing and integrating modular courseware to support the capstone project.

Enhancement of Manufacturing Process Laboratories and Courses

The proposed manufacturing process laboratory and course enhancement will implement the following:

- Incorporate manufacturing process control concept into each course for specific manufacturing processes. For example, in the machining process, existing facilities will be further developed to introduce machine tool metrology, assessment of machine tool accuracy, collection and analysis of manufacturing data, and use of design of experiments to analyze the data. This will give the students the required hands-on training and experience and will enable them to establish quantitative relationships among material properties, processes, and the various process variables that govern the quality, productivity, and cost of the manufactured product. This type of experience is missing in the present course structure.

- Make a concise multi-media web-based module to introduce a specific process so that students in the capstone project can use it as a reference in optimizing the product realization process. The developed laboratory experiments will be documented as a laboratory manual in multi-media format.
- Incorporate computer modeling and simulation of each process to provide in-depth understanding of each process and on-line accessibility to students so that they can have some level of understanding of each process even if they do not have previous experience. The availability of PC-based modeling and simulation packages provides an opportunity to integrate the modeling and simulation aspects of manufacturing in the conventional courses. This accessibility will introduce the students to the latest tools available to industries and prepare them for innovations in manufacturing processes.

Modular Courseware to Support the Capstone Project

We will adapt, develop, and implement modular courseware to support the two-semester capstone design course. As mentioned previously, this project-oriented course will be 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 propose to adapt, develop, and use multimedia modular courseware to enable the students to effectively communicate with each other and execute the project. The courseware will be web-based and/or video-based; special attention will be paid to make self-paced student learning occur. As part of the background work, 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/TRP[13]; 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 NSF[12]; 3) Undergraduate engineering education projects such as SYNTHESIS Coalition[16] and SUCCEED (NCA&T)[15] funded by NSF; 4) The Multimedia in Manufacturing Education project at Georgia Tech[7]; 5) The Best Manufacturing Practices (BMP) program sponsored by the Office of Naval Research[3]; 6) The Stanford Global Supply Chain Management Forum[14]; and 7) North Carolina Consortium for Logistics Education[8] funded by NSF.

The course modules from the above-mentioned resources will be adapted and integrated to support the capstone project course. They will be self-contained, with practical examples, and fully accessible to students through the web and/or video. We expect that each course module will take 5 to 15 hours to learn depending on the complexity of the subject. The modules that we plan to adapt and implement for the capstone course are shown in Table II. They include:

1. Team-based product development module: including the basic concept of concurrent engineering, i.e., how engineers work together in design, manufacturing, and marketing, and

how to form teams and work with others with different technical backgrounds to achieve project success.

2. Project management module: including basic project management, such as how to define project objectives based on customer requirements, TQM (Total Quality Management), project planning and scheduling, and decision making.
3. Supply chain management module: covering important issues relating to the design, development, and performance measurement of a supply chain network that include make/buy decision, how to select catalog part suppliers and vendors, and job-shop vendors and suppliers who accept designs from clients.
4. Product marketing and cost analysis module: including product market survey, definition, cost analysis, and actual selling of the product.
5. Product assembly module: including how to put parts together, and its impact on manufacturing processes. This knowledge will be required for projects involving multiple components to form an assembly.
6. Manufacturing case library: Each capstone project team will be required to document their project through a multimedia presentation and report. A library collecting these reports, to be maintained by UMR's MEEP, will be 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. This library will also be accessible to other institutions through the Internet.

Course module	**Adaptation sources (references)**	**Effort in the adaptation process**	**Delivery method(s)**	**Module Learning Time**
Team-based product development	13, 16	Medium	Web, video	5 hours
Project management	13, 16	Medium	Web, video	5 hours
Supply chain management	3, 8, 14	High	Web, video	15 hours
Product marketing and cost analysis	13	High	Web, video	10 hours
Product assembly	13	Medium	Web, video	15 hours
Manufacturing case library	7	High	Web	10 hours

Table II. Adaptation and Implementation of Course Modules

VII. <u>Partnerships with Industries in the State of Missouri</u>

Students will be given real-life projects based on manufacturing processes and will be 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.

At present there are ten members in the Industrial Advisory Committee of UMR MEEP: The Boeing Company in St. Louis, Missouri; Briggs & Stratton, Rolla, Missouri; Caterpillar Inc., Peoria, Illinois; General Motors, Inc. Lansing, Michigan; Honeywell, Kansas City, Missouri; Lemay Center for Composites Technology, St. Louis, 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. The members expressed their strong support for the proposed new manufacturing engineering curriculum and their interest in working with us to develop this curriculum. In addition, advisory board members of FV's program will also be invited to participate in this program.

VIII. Conclusion

This project is being implemented at UMR and FV. The capstone project course is structured so that its format conforms to the participating institutions' basic requirements and that existing resources such as faculty and technician support can be fully utilized. Although the proposed project is currently aimed at curriculum development for undergraduate students with manufacturing options and manufacturing minors, many of the course modules will be made available to other programs in manufacturing, including distance-learning education for engineers in industry. We believe the proposed approach will have excellent potential for replication by other institutions. The following have been identified as good opportunities in terms of replication potential:

1) This proposed effort will integrate the existing campus manufacturing resources and those available from industries to provide distributed manufacturing experiences for students. The collaboration between UMR and FV will integrate engineering and technology to solve real problems in industry. We plan to use this experience to work with other local community colleges to enhance the manufacturing program in Missouri. This model can also be adapted at other institutions that have limited manufacturing process facilities.
2) The interdisciplinary team-based format for capstone course will be very different from the traditional senior design projects in which most students have similar technical backgrounds. An interdisciplinary team will provide the students with the experience of solving a problem using various team members' expertise. This will be an excellent model, which can be replicated by other institutions.
3) The proposed capstone project course, which provides opportunities for students to design, manufacture, and actually market a product, will be able to stimulate students' interest in real-world product realization. Business knowledge and skill will be naturally incorporated into consideration in students' design and manufacturing.
4) In the traditional engineering curriculum, manufacturing process, classes are normally separated from quality control classes. However, it is important to let students learn about how to measure variations, understand process capability, and control the processes. This proposed program would use a systematic approach to include process control into various processes. This approach will provide more in-depth knowledge to students when process control is introduced in each specific manufacturing process. Each process will be documented into web-based multi-media courseware as a reference for students in the capstone class. It will be also available for dissemination to other institutions for replication.

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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.