Teaching Manufacturing As Concurrent Engineering Design

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Abstract

The National Research Council's report on Competitive Design stressed that teaching and practicing Concurrent Engineering is the best way for America to improve its global economic position. A central theme of concurrent engineering is the consideration of manufacturing process design in the early phases of the overall system design. Unfortunately, over the years, courses teaching manufacturing process have been removed from many undergraduate curriculums. The University of Alabama now offers an integrated pair of courses on manufacturing processes and design. A central theme behind the courses is that manufacturing topics are cast in a concurrent engineering design context. The introductory first course is taught at the junior level, while the second course is a more comprehensive senior offering. Both courses require the student to participate in *design and build* projects. The students are placed in teams and must learn to communicate and work effectively in the team environment. Further, both courses make use of the state's educational manufacturing resources in a novel, collaborative arrangement. This approach allows the institutions to better leverage state resources which allowed The University to implement these courses without purchasing new manufacturing lab equipment.

Introduction

The United States' negative trade balance has steadily increased over the last several decades. The National Research Council report Improving Engineering Design [1] cites manufacturing goods as a primary contributor of the trade deficit. They concluded the best way to correct this is for concurrent engineering techniques to be practiced by industry and taught by the engineering educational establishment. Manufacturing courses taught in the traditional hands-on laboratory format have fallen from vogue as they were viewed, often unfairly, as lacking sufficient scientific content. As a consequence, many engineering schools dismantled their manufacturing process laboratories. Attempting to rebuild the labs is prohibitively expensive, especially in light of budget concerns and the explosion in new equipment technologies. Another complaint about traditional manufacturing courses having a "hands-on" lab was that it only trained students to be "shade tree mechanics" and not "real engineers". Simply reimplementing the traditional course can not overcome these deficiencies. Several curriculums have implemented a lecture based survey course to make students aware of manufacturing topics. Lecture courses, by their very nature, are incapable of conveying an appreciation for manufacturing issues that the hands-on labs can achieve in a limited fashion. In either case, the traditional approach does not convey the interaction needed between the product and manufacturing process design stems necessary to produce a successful product. The student is expected to make this connection intuitively.

While many colleges and universities have lost their manufacturing facilities, vocational and technical schools have done better in maintaining and even improving their capacities by incorporating new technologies and equipment into their programs. Also, many states have, or are in the process of establishing, manufacturing technology extension programs to assist local industry to compete in the global market while still coping with federal government cutbacks. Strategic coupling ofalleducational resources cansignificantly enhance any engineering curriculum's design component. This paper discusses how The University of Alabama (UA) merged these different resources in teaching a pair of integrated manufacturing and design classes.

Introductory Class-Introduction To Manufacturing Processes

The introductory junior level course consists of a two credit hour lecture and a one credit hour lab. The lecture includes a survey of traditional manufacturing processes, as do most courses of this nature. However, the underlying emphasis is to focus the student on how manufacturing issues affect product design. A unique aspect of the lab is that it is collaboratively taught at a nearby junior college using their shop facilities. As part of the lab, the engineering students learn about and practice basic machining skills, in a hands-on setting, while apprenticed to senior students of the technical school. The connection between design and manufacturing is reinforced by having the engineering students design a part using, as a minimum, sophomore level engineering science skills. Students further along in their studies use more appropriate analysis skills. The connection between design and manufacture is solidified by teaming the engineering students with their technology student-mentor to complete the design and build as a "team" effort. Collaboration between the two disciplines; i.e., engineering and skilled trades, is continually stressed. During part(s) fabrication, the engineering student is restricted from participating in the actual production. Rather, they only monitor and direct the technology student to insure the project stays on schedule. This course teaches manufacturing processes from a design perspective while developing a team mentality to insure the project's successful completion. It also instills in the students that they must work together as a cooperative team, not as adversarial partners.

Course Goals

The five main goals to this course are:

* introduce the engineering student to manufacturing processes and terminology,
* provide the engineering student a hands-on experience that fosters an appreciation for manufacturing implications on the design process,
* provide the engineering student with a "successful" and fun first design and build experience,
* stress communication and teamwork skills in the modern production environment, and
* introduce the application of concurrent engineering skills on a small scale project.

The first two goals are typical of any introductory class. The latter three provide the student with an awareness of how things are practiced by American industry that are implementing concurrent engineering. The contrast in work environment between the traditional undergraduate engineering educational experience and the industrial sector can be extreme and often the applicability of the engineering education sciences are not readily obvious to the young engineer. This course fosters the needed real world skills in a structured learning situation.

A widely held sentiment by many engineering and industrial firms, as expressed at recent manufacturing conferences [2, for instance] is that engineers who can work effectively in interdisciplinary teams have to be found and nurtured or else removed from the engineering design process. This view is reinforced by new ABET guidelines [3] stressing vertically and horizontally integrated design in the curriculum. Other studies by academic and industrial task forces defining the desired role for engineering education concur. [4]

Course Implementation

The course consists of a two-hour lecture credit and a one-hour lab credit and has corequisites of both a materials and strength of materials class. These were made corequisites instead of prerequisites simply because Industrial and Metallurgical engineering students take this class and do not take these classes until juniors. The lecture and lab components are integrated through the design-and-build project. To maintain course control for accreditation purposes, the coordination and responsibility for both the lecture and lab components rests with the university faculty member. Small lab sections of 4 or 5 engineering students are conducted with the engineering students being in the machining lab at the same time and shoulder-to-shoulder with the technical school students. Lab topics and exercises are coordinated with the lecture material.

Lecture Course

The lecture course is designated as ME 383 and taught at the junior level. It is mainly a survey course presenting a wide variety of traditional and non-traditional manufacturing process topics as shown.

* design for manufacturing
* material properties & selection
* machining processes
* joining methods
* composites
* comprehensive examples to tie things together
* drawing and tolerancing
* metal properties
* metal casting & forming
* plastics
* CAM/CIM

Supplementing the lectures are case studies. These come primarily from the ASEE Case Study Library at Rose Hulman University. [5] These are assigned as reading material and integrated into class discussions. Several field trips are taken to local industries to demonstrate various processes in a production setting. The engineering project teams are formed and the design effort completed in this portion of the course. Teamwork and communication are reinforced between the two student groups as the technology students accompany the engineering students on the plant trips. Quizzes and tests have questions covering the plant trips. These questions are designed to encourage the students to be active learners as opposed to passive listeners.

Laboratory

The laboratory portion is taught at nearby Shelton State Community College (SS) in their Machine Tool Technology Department's facilities as ME 283 at UA and MTT 283 at SS. The lower number prevents a junior college from assigning junior level engineering credit. Though unusual, this satisfies ABET accreditation.

The students attend lab once a week for three to four hours. The teaching shop at Shelton State offers a large variety of traditional and non-traditional, manual and numerically controlled equipment. The technical school instructor provides overall guidance while the senior technical students provide one-on-one mentoring and assistance that implement the training on several production exercises using different machines. The engineering students use measuring equipment to learn about tolerancing, drawing, and blueprint interpretation (from the skilled trades perspective) by reverse engineering simple parts. Finally, students are introduced to CAD/CAM and use commercial software to develop simple NC code. The major lab activities include:

* sketching and blueprint reading
* manual lathe operations
* welding
* demonstrate CNC operations
* use of measurement equipment and tolerancing
* manual mill operations
* CAM development of CNC programs
* demonstrations of non-traditional operations

The lab concludes by instructing engineering students how to use equipment in the UA student machine shop. This is important because successful completion of this course is one way engineering students gain access to the shop. Such access has been particularly valuable in supporting many student's in their senior Capstone Design projects plus extracurricular activities such as the mini-baja and natural gas challenge.

Project and Concurrent Engineering

The integration of the two components of the introductory course occurs early in the semester when students from both institutions are brought together to form the project team. Successful completion of the course requires the students to design and build a useful component. The project structure forces the students to develop effective communication skills between the engineering students and the technical disciplines as well. All learn project management techniques and practice acceptable reporting methods.

The students can define their own project, select one from a list of departmental/faculty needs, or work on a local industry sponsored topic. Partnering with local industries is encouraged as it develops better working relations between all parties and aids The University at providing an engineering education more in line with industry needs. To date, projects have been suggested by students, the local GM facility, NASA, a local chicken producer, and faculty. Examples of projects include: a hunter's tree stand, an adjustable load cell fixture, lab equipment, a controlled cleaning mechanism for an animal feeding system, and various positioning fixtures.

The engineering student's responsibility includes developing the conceptual design, preferably with input from the technical students, and performing the detailed design and analysis which includes the drawings and bill of materials. The technical student, along with the engineering student, develops the manufacturing plan, milestone chart and produces the part under the "manufacturing" engineering student's guidance.

Introductory Course Synopsis

This course has been a tremendous success and has generated significant student interest. Each of the five times it has been offered, demand has exceeded capacity. In fact, recent faculty limitations prevented it from being offered, so approximately 90 percent of the graduating upper class petitioned to have it added. Fortunately we were able to grant the petition at the last moment.

One of the greatest successes of this course is the interaction between the two student groups. The students experience a real world, often adversarial, relationship and learn to cope. Because of the setting, most students complete the experience with a positive outlook concerning future interactions with others. However, there are two major drawbacks. First, is the coordination required between the schools and second is the expense associated with any "build" project. Administrative support from both institutions overcame the first obstacle while a start-up grant from the Alabama Space Grant Consortium [6] eased the second, at least for the first year. Local industry, student initiative, and departmental assistance is now used to defray costs.

Modern Product Realization

The second course builds on the first course by implementing a three hour lecture period of advanced manufacturing and design topics with a one hour advanced lab. The lab utilizes the facilities of The Bevill Center for Advanced Manufacturing Technology, located in Gadsden, Alabama. This course has been taught twice and each time teams of three or four people were formed. Included on the team have been students from metallurgical and mechanical engineering. The course philosophy has each team represent competing companies who were contracted to produce a working prototype. The company with the "best" prototype wins the follow-on, large scale production contract. To win, a manufacturing plan and economic analysis were done to determine if the mass production was feasible and profitable for the company.

Because of the distant location from The University, this course is only offered during a summer session. The primary thrust of this course is to form multi-disciplined teams to develop a design concept, perform the detailed design analysis, and produce the prototype of the complex product. As part of the effort the students learn and practice: effective work delegation, material specification, design skills--both conceptual and detailed, and modern communication skills. Computer Aided Design tools are (reintroduced to the students for use on the project. While at the remote location, the students are mentored by the Bevill Center staff. To foster development of effective communication skills, students utilize modern communication devices such as fax, long distance conference calls and direct interactive video links for video conferencing.

Course Goals

The objective of this course is to provide an in-depth, meaningful hands-on experience that encompasses the spectrum of topics needed to produce a successful design in a very short time frame. The modern product realization topics the students are introduced to include:

* teamwork and communication
* computer aided engineering and design tools such as FEM, CAD, CAM, CIM, etc.
* assembly considerations
* modern communication technology
* conceptual design using facilitated brainstorming
* materials: selection and procurement
* manufacturing processes for production planning
* economic considerations

Course Implementation

The course, as implemented, is roughly equivalent to the senior capstone design project, but it requires a product be manufactured which is not always the case with the capstone project. Since this is an elective course, students taking this class have a second design project that is in addition to the required Capstone design project. The students are given a short problem statement with a limited amount of background information about the hypothetical project company they are employed by. From the problem statement, they formulate the functional and/or needs requirement(s) which leads to generating a statement of work. In the industrial world this forms the basis of the contractual relation between the parties. After this, they advance to the conceptual design which includes a facilitated brainstorming session to assist them in developing at least three workable concepts. A detailed weighting analysis of which concept is best is not pursued due to time constraints, but each team must make a presentation justifying why a specific concept was selected. The presentation is critiqued by management (instructors) and the competing team(s). Any deficiencies must be corrected before management approves the selected concept. Once approved, the detailed design commences and it is here the teams begin to practice true concurrent engineering. The detailed design includes any and all necessary analyses, bill of materials, all purchase orders, and a set of computer generated working drawings. One artificial constraint imposed on the design is that at least one component be cast and the casting done prior to leaving for The Bevill Center. The part is made at the metal casting facility at The University. Students are taught pattern design basics to design their patterns and the associated rigging. They follow this by assisting in making the mold and the actual pour. These initial phases are conducted at The University and takes about two weeks.

At this time the students are sent to The Bevill Center in Gadsden. There, they receive more hands-on experience through small exercises to learn about CNC, CAM, and CIM software and hardware. In conjunction with these exercises the teams continually update their design and analyses as changes are needed. They oversee the parts production by the Gadsden staff while doing any finish and assembly work, parts tracking, and needed video conference calls to management (faculty back at The University). Video-conferencing is used to provide interim project briefings and receive additional lectures concerning engineering economics, make or buy decisions, and reporting requirements. At the end of the three week Gadsden stay, the teams make a formal presentation to company management (all faculty and staff involved). This is culminated with a formal written report. However, as with most engineering projects, success is ultimately determined by a working prototype coupled with full production and economic plans. Hence, the students must demonstrate a working prototype.

Project Overview

The two projects used to date included a specialty hand press that could be automated at a later date and a jack-winch combination. Particular constraints for the first course offering was the development of a specialty press that could be manufactured for $100 and sold at no more than a 100% markup. The main structural member had to be made from ductile cast iron. The resulting designs utilized rack-and-pinion and screw-jack style mechanisms. The second project redesigned a carjack to include a winching feature that could be sold as an optional upgrade for the new Mercedes-Benz All Activity Vehicle being manufactured nearby. In this case, the winch add-on had a projected volume of 115,000 units over three years and Mercedes would purchase them for $85. The teams were allowed to specify which part was to be cast.

Advanced Course Synopsis

This class is marked by the students logging very long hours to complete the project. Despite the difficult nature of the class, no student has complained about the effort required. Rather, on course evaluations and the senior exit interviews, they continually comment that this is the best class they had. The only negative comment is that business students are not included. The students think this would be a definite improvement as business students would participate in a *real* engineering process, while the engineering students would participate in marketing decisions. This would allow students from each discipline to understand the needs and criteria of the other group. The students felt being teamed with business students would result in more realistic economic analysis. Plans, much like the graduate enterprise programs offered by Stanford and Michigan [7, 8], have been made to include business students in the future.

A major drawback to this class is the restriction on size due to limited facilities for housing the students at the remote site. The Capstone Engineering Society, a College of Engineering support agency, owns a four bedroom house across the street from The Bevill Center for student or faculty use. This allows eight students per term to be housed without additional expenses. Any number of students over this limit requires the student to provide their own accommodations. Coordination of the class would be impossible except for the excellent working relationship between the staff at The Bevill Center and the engineering faculty at UA.

Conclusion

Two elective mechanical engineering courses have been developed to offer undergraduate engineering students an integrated sequence in which to learn design and manufacturing issues under a concurrent engineering envelope. Two faculty members in the Mechanical Engineering Department team-teach the classes. (One of the members has since left The University.) The remaining faculty member has an extensive industrial background in design and manufacturing, and his work related experiences are used to supplement case studies.

The Departments of Industrial, Mechanical, and Metallurgical and Materials Engineering have had a manufacturing certificate program, but little student interest was shown in the program until recently. These new courses have been integrated into the program and are partly responsible for its revitalization. Both classes are presently electives within the Mechanical Engineering Department although student request for participation is increasing and this has created a mood to make the introductory class mandatory.

The introductory course has been so well received by both the students and faculty that the Metallurgical and Materials Engineering Department now accept this course in lieu of their required senior manufacturing processes class. To date, sixty students have participated during the past two and a half years and currently fifteen are enrolled after we added the section requested by the student petition drive. The follow-on class has had thirteen students participate the two summers it was offered. The increased demand for the introductory course has required Shelton State and The University to explore ways to increase lab enrollment capabilities without detracting from the primary mission of Shelton State. Completion of the introductory course is one way access to the recently established student machine shop is gained. The shop is another resource to support other activities like the SAE mini-Baja, Natural Gas Vehicle Challenge, and the Capstone Design Class.

Finally, these two classes form part of the framework for an automotive engineering and manufacturing technology center being established in conjunction with the nearby Mercedes-Benz manufacturing facility. The introductory course is described further in references 9 and 10 while reference 11 addresses the second.

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