

Integrating a Manufacturing Technology Program into Engineering Capstone Design

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The Mechanical and Mechatronic Engineering programs at California State University Chico conclude with a common two-semester course sequence in capstone design. Projects are generally sponsored by industry and all work is accomplished in teams. The first semester focuses on design while the second is dedicated to building and testing a working prototype. The department also houses a degree program in Manufacturing Technology. A new paradigm has been instituted that integrates the manufacturing technology program into engineering capstone design.

A major element of capstone design at California State University Chico is the requirement that student groups build and test a working prototype. In many cases, prototype construction becomes an unintended hurdle for completion of capstone course requirements, as many engineering students do not possess basic fabrication skills such as machining and welding. By contrast, students in the manufacturing technology program do possess these skills, and also require practice in their application as part of their curriculum.

In the new paradigm, manufacturing students work with engineering project teams during prototype design and construction. The manufacturing students don't just "make parts," but consult on many aspects of the project with a focus on design for manufacture. They offer insights into the manufacturability of proposed designs, and even suggest minor design changes that often substantially ease fabrication and significantly reduce cost without altering the end function of the design.

The new paradigm takes advantage of the differing focus of the programs as well as the unique skill sets of their students to the mutual benefit of both.

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Overview of Capstone Design

As with many engineering programs, the mechanical and mechatronic engineering curricula at California State University Chico utilize a two-semester capstone course in senior design project. The intent is for students to utilize competencies developed in the first three years of the curriculum in the solution of a real-world design problem. The first semester is predominantly spent in design activities, while the second encompasses prototype building and testing. Projects are primarily sponsored by local industry, which is a recent focus of the program. This new approach of generating projects through industrial partnerships is consistent with many capstone engineering courses nationwide¹.

During the first semester, weekly lectures are given that cover many aspects of the design process. Selected topics include customer requirements and specifications, conceptual design, decision making, project management, cost estimating, budgets, documentation and formal reports. Each project group is required to give three oral presentations during the semester. The

presentation topics are project proposal, midterm review, and final design. The semester concludes with submission of a comprehensive design report.

The spring semester includes less time in the classroom and more time spent building and testing the designs. Students are required to develop a comprehensive test plan to prove the specifications developed in the fall semester. They then fabricate and test the design, and in most cases, proceed directly to redesign activities. The semester concludes with a final oral presentation, a poster and display of the prototype, and submission of a comprehensive written report.

The design projects are accomplished by student groups², as the ability to work in groups is one of the measured outcomes of the course. Groups typically number about four, but may vary based on the complexity of the assigned project. Groups may be made up entirely of mechanical engineering majors, or may also include mechatronic engineering majors depending on the technical aspects of the project. Regardless, each group is assigned a single faculty advisor³ for the duration of the project.

Common Issues

Capstone design is like no other course in the curriculum, and provides a unique experience for both students and faculty. From the student's perspective, there are neither tests nor homework, but anecdotal evidence suggests that much more time is spent on capstone design than on other courses in the curriculum. All work is accomplished in a team environment, and students' grades are dependent to a large extent on the work of others.

From the faculty member's standpoint, capstone design includes many complications not found in other courses. A short list of challenges unique to the course includes project selection, project scope, team assignments, team member compatibility, and project advising, as well as a host of other issues.

But one of the most significant hurdles faced by students in the class, which can also create challenges for the faculty member, is prototype construction. Students in the class are required to build and test their designs. This means producing either a full scale final product or at least a working "proof of concept" prototype. The working hardware is then tested to demonstrate that all customer requirements have been satisfied.

Many students in the class have some basic hands-on skills, and a few even bring past experience in mechanics, machining, welding, and other trades. But for a significant portion of the class, their only experience base in these areas is a freshman level course in Manufacturing Processes. The course is designed to familiarize the student with the basic concepts of manufacturing, materials, and processes, but does not provide even basic competency in these areas.

Depending on the make-up of individual student teams, many groups struggle with the prototype construction phase of capstone design. Support is available from technicians employed by the college, but they are a limited resource and there is often competition for their services. Oftentimes, tasks as simple as machining a bracket to support a motor housing can seriously delay the completion of a prototype.

The Manufacturing Technology Program

In addition to programs in Mechanical and Mechatronic Engineering, the department also houses a Bachelor of Science degree program in Manufacturing Technology. The manufacturing program is a practical, applications oriented, hands-on curriculum that blends metals manufacturing, polymers manufacturing, and automation with business and management⁴. It prepares students for a variety of manufacturing careers ranging from management of manufacturing facilities to research and development to technical sales. The

program is accredited by NAIT (The Association of Technology, Management, and Applied Engineering⁵, formerly known as the National Association of Industrial Technology).

Compared to an engineering program, the manufacturing technology curriculum has less emphasis on mathematics, stopping at pre-calculus, but still contains basic courses in physics chemistry, graphics, and of course, general education. The program includes numerous core manufacturing fundamentals, such as material removal, computer-aided manufacturing, automation, plastics, polymer materials, industrial safety, and project management. The program also has a business emphasis, with coursework in economics and accounting.

The manufacturing technology program has several clearly defined educational objectives. Based on these objectives, program graduates are expected to:

- have a thorough understanding of how products are designed, produced, and tested
- have a thorough understanding of contemporary manufacturing processes, particularly for parts consisting of metals and polymers
- understand the fundamental behavior of various materials and the testing used to determine material properties
- have an understanding of project management, quality assurance methods, and the economic issues involved in manufacturing
- be familiar with contemporary computer applications and process automation, including the use of sensors, actuators, and controllers to automate machines and processes
- be practiced at communicating ideas in oral, written, and graphical form
- be able to function effectively as team members

While the engineering and manufacturing programs are offered in the same department, and share a common faculty and have some identical coursework, the emphasis of the programs is clearly different, and the graduates obviously possess sharply different skill sets.

Manufacturing Students

While some students choose the manufacturing technology program as entering freshmen, many transfer in after a year or two in one of the engineering programs, usually after deciding that the practical, hands-on curriculum is a better fit for them. Anecdotal evidence from current and past students suggests that many begin study in engineering, particularly in mechanical engineering, due to a general interest and aptitude in certain hands-on activities, such as automobile mechanics or even machine shop work.

These students have many common qualities, such as the desire to know how things work, the propensity to take things apart, and basic competency in many tools and trades.

But when these students embark on the typical freshmen year engineering curriculum, they are often disillusioned, and struggle to connect early course work in chemistry, English, physics, and in particular, calculus, with the mechanical aspects that led them to study engineering in the first place. Indeed, such courses have been cited⁶ as a primary reason for students not persisting in engineering programs.

Many, many students at California State University Chico have excelled in the manufacturing technology program after experiencing academic difficulties in an engineering program. These students possess skills that many employers covet, and very few graduates have trouble finding gainful employment.

Changes Create an Opportunity

Though the engineering and manufacturing programs have existed in the same department for years, there has historically been very little interaction between the respective programs and students. Based on recollections of senior faculty, early attempts to involve manufacturing students in capstone design were attempted, but were ultimately not successful and were abandoned. The primary reason cited was friction between the groups based on the characterization of engineering students as “management” and manufacturing students as “labor.”

Since that initial failure, several things have changed within the department, providing a new opportunity for collaboration. The primary changes involve new faculty members on both sides, each with a genuine appreciation and respect for the other’s programs and students. Another change is fiscal in nature, with reduced technician resources available to support the capstone design program. In the recent past, capstone design teams have had to rely on their own skills, or use sponsor funds (or fund-raise) and pay outside sources for basic machining and/or welding services.

A final element was the interest and willingness of a key manufacturing student to spearhead the effort and see through its implementation.

A New Paradigm

With a clear need of manufacturing support for capstone design, and a supply of talented manufacturing students in the same department, it seems obvious that manufacturing students could assist engineering students in fabrication of their capstone design projects to the mutual benefit of both parties. And while this idea seems fairly simple on the surface, successful

implementation requires attention to many details and careful consideration of several factors.

The first major consideration is the seemingly simple matter of deciding at what point in the design process to involve the manufacturing students. There are compelling arguments to engage them in early in the process, perhaps as early as the transition from conceptual design to detailed design, which occurs about two-thirds through the first semester. The idea behind early involvement is that based on issues of manufacturability, the manufacturing students could suggest minor design changes that could potentially ease fabrication and reduce cost without altering the end function of the product.

But there are difficulties and concerns with this approach, chief among them being a potential negative impact on group dynamics within the engineering design team. The engineering students are responsible for their design, and being told early in the detailed design phase that certain things need to change may cause unnecessary friction and consternation within the team. While the actual designs would probably benefit from early input from manufacturing, the design teams themselves probably would not.

We have found that it’s best to let the engineering students complete detailed design, including all working drawings, before receiving input about manufacturability. The students are typically very busy during the detailed design phase, and usually struggle just to complete the drawings and report by the end of the semester. It’s better to let that process run, then revisit the design in the spring when preparations for prototype construction get underway.

Another major consideration is the mechanism for getting the two groups of students together. Do you randomly assign one or two manufacturing students to each engineering design team? Do you force them to meet and then have the groups report back to their advisor what transpired in the meeting? Clearly, there is great potential for friction between the students if any type of mandatory interaction is prescribed.

Rather than force manufacturing student involvement in capstone design, we have found it more effective to offer manufacturing support to the design teams, and to make it available as the need is first perceived.

Early in the second semester, when the design team’s focus has turned to fabrication, the potential support from the manufacturing students is introduced to the class. Ideally, a key manufacturing student is selected to speak to the capstone design class about their potential services. We have found that offers to help with machining and welding are often very well received at this point. And with the right emphasis from the course instructor, the subject of design changes based on manufacturability can be successfully broached, often with willing acceptance from the

engineering design teams. A vital component of the success of this paradigm is the empowerment of the manufacturing student to suggest design changes based on manufacturability. This empowerment is best established by the course instructor.

A final issue with implementation of this paradigm is the actual mechanics of scheduling, accomplishing, and funding the work done by the manufacturing students. We have managed this through the student chapter of the Society of Manufacturing Engineers (SME), the principle professional society in the field of manufacturing. Engineering project teams supply raw materials and in addition make a donation to the SME chapter in exchange for work done by the manufacturing students. Rates and amounts are negotiated by the students, with involvement from faculty advisors (of both SME and the project teams) as needed.

Benefits to Both Sides

The new paradigm has clear benefits for the engineering students, as they receive manufacturing support that significantly eases construction of their prototypes. But more importantly, they see first hand the importance of design for manufacturability, and the associated cost benefits that it affords. They also gain an appreciation and respect for the manufacturing profession, whom they will likely be working side by side with in industry.

The benefits for the manufacturing students are quite different than those of the engineering students, who are receiving academic credit and are fulfilling a graduation requirement. By contrast, participation by manufacturing students is entirely optional. They receive no academic credit and the work is not a formal part of their curriculum. Instead, their participation is driven by upper division students who recognize the opportunity to not only apply what they have learned in their program, but to also expose lower division students to the tools, techniques, and practices they will soon see in their coursework.

Most of the group interface and design suggestions are handled by the experienced upper division students. But the actual fabrication support is often accomplished by lower division students under their supervision. The younger students are exposed not only to the fabrication techniques, but to the impact of design decisions on manufacturability.

The key to securing participation by the manufacturing students lies in their recognition of the advantages of doing so. They are afforded practical application of their coursework and exposure to real world design projects. They generate funding for their student professional chapter, which supports many of the extra-curricular activities within their program.

Finally, they recognize the value of providing to provide practical experience for their lower division students.

Requirements for Success

Clearly the success of this paradigm relies on the active participation of all stakeholders. The engineering students must be willing to accept suggestions from the manufacturing students, and need to recognize the advantages of their different skill set. The course instructor and faculty advisors must also support this notion, and must communicate it effectively. Finally, the manufacturing student leaders must recognize the benefits of their program's participation, even though it's not required and no academic credit is received.

This new paradigm has its challenges, but it also has tremendous benefits for both programs' students. It is a partnership with mutual benefit that goes well beyond the simple "making of parts." It closely approximates the environment that many students will experience in the workplace, and fosters an appreciation for each other's unique perspective and skills..

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