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AUTHOR Durfee, William K.
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ABSTRACT

The Department of Mechanical Engineering at the University of Minnesota developed a new engineering design curriculum to meet the pedagogical needs of undergraduate and graduate engineering students and to excite and retain engineering students of both genders and from all backgrounds. The curriculum is based on a series of guided, hands-on experiences and significant collaboration with industry. The cornerstone of the undergraduate program is a new introduction to engineering course that teaches through product dissections and creative hands-on activities. At the graduate level, teams of business and engineering students undertake product development projects in collaboration with sponsoring companies. The resulting level of interaction between the university and industry has been shown to benefit students, faculty, and partner companies without requiring the expenditure of significant university resources. The curriculum's designers offered the following lessons for others considering similar programs: (1) engineering and business must lead the program equally; (2) creating appropriate confidentiality and intellectual property policies and agreements takes time and requires considerable negotiation between company and university lawyers; (3) the course's formal academic component should center on learning a product development process; and (4) close geographic proximity between company and university leads to greater company-university interaction. (MN)

TEND 2000

Crossroads of the New Millennium

A Successful Engineering Design Education Program Incorporating "Hands-On" And Interaction With Industry

Prepared and Presented

By

Dr. William K. Durfee

Associate Professor

Mechanical Engineering Dept

University of Minnesota

email : wkdurfee@tc.umn.edu

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Workshop 1

Abstract

The Department of Mechanical Engineering at the University of Minnesota has developed a new engineering design curriculum to meet the pedagogical needs of undergraduate and graduate engineering students and to excite and retain engineering students of both genders and from all backgrounds. The programme is based upon a series of successful, guided, hands-on design experiences and significant collaboration with industry. The cornerstone of the undergraduate programme is a new introduction to engineering course that teaches through product dissections and creative, hands-on design activities. At the graduate level, product development projects are undertaken by teams of business and engineering students in collaboration with sponsoring companies. The resulting level of interaction between the university and industry benefits students, faculty and companies. These initiatives demonstrate that it is possible to have students of all levels experience real-world, hands-on design without requiring significant university resources. Co-operation with local industry ensures that business and university can work together to optimise the value of the educational experience for the engineering student.

A Successful Engineering Design Education Program Incorporating "Hands-On" And Interaction With Industry

INTRODUCTION

Engineering design education is at a crossroads with significant programmemematic changes occurring in schools throughout the world. The history of engineering education reveals a pendular motion as theories of the best way to educate engineers evolve. Prior to the Second World War, education was synonymous with practical training, with students learning to run machinery and solve problems through extensive hands-on experiences in the laboratory. In the United States this changed suddenly in the Cold War era when the Soviet Union launched Sputnik, the first successful orbiting spacecraft. Education leaders realised that future success for the country depended on graduating engineers skilled in the engineering sciences. The steam engine laboratories and shops disappeared, replaced by courses relying on advanced mathematics and physical principles. The fields of information theory, thermodynamics and chemical kinetics fueled the advances in radar, communications, rocketry and aerodynamics that marked the 1950s through the 1970s. The pendulum had swung completely away from hands-on.

Since the late 1980s, there has been a growing realisation that the pendulum had traveled too far. Universities were graduating engineers highly skilled in mathematics and engineering sciences, but weak in problem solving skills and lacking in design experience. The debate was fueled by the perception that methods of teaching design that may have worked in the past were no longer appropriate for the current era of intense global competition, pressure to be first to market and increased emphasis on quality that dictates the success of modern products. Industry also became increasingly uncomfortable with how designers were being educated. Industrial leaders called for a broadening of the scope of education rather than additional training in specific technical skills. The new product design leader must not only be technically competent, but must also be able to define the needs of the customer, assimilate and manage the flow of information associated with a project, work in or manage a large team with members from many departments across the company, and produce results under the tight deadline of a rapid product design cycle.

The solution has been a gradual return swing of the pendulum with engineering schools recognising that students need a mix of engineering sciences coupled with hands-on design experiences to truly appreciate when the equations work and when equations get in the way.

In the United States, the result has been the creation of exciting engineering education programmes designed to excite, motivate and retain students while providing a very realistic engineering experience within the guided, education structure.

In this paper, we examine how such a programme was created and implemented in the Department of Mechanical Engineering at the University of Minnesota in Minneapolis, Minnesota, USA. The University of Minnesota is one of several large, public land-grant universities in the United States. It is the flagship school for the state of Minnesota with 246 degree-granting departments and 46,000 students. The engineering school has approximately 4,000 students of which 800 are enrolled in mechanical engineering, 500 undergraduates and 300 at the graduate level. The University of Minnesota has been consistently rated as having one of the top 10 mechanical engineering departments in the United States. The department offers a full complement of basic and advanced courses in topics ranging from fluid mechanics to kinematics to combustion to robotics.

Prior to the new programme, there were very few hands-on design experiences for undergraduates and none at the graduate level. Further, there was little interaction with industry, despite the rich, high-technology industrial base in the Twin Cities of Minneapolis and St. Paul. The objective of the new programme was to correct these shortcomings and demonstrate that a hands-on approach, coupled with significant industrial collaboration could result in a much stronger educational experience for the student with a positive benefit to the Twin Cities region and the state of Minnesota.

INTRODUCTION TO ENGINEERING COURSE

The goal of this course was to change the way in which design was taught at the University of Minnesota, and thus serve as a model for design education at any large, public university. In particular, the faculty was interested in returning a hands-on design component to engineering education and having design be a unifying theme throughout the student's undergraduate programme.

A particular objective of this curricular project was to demonstrate that hands-on projects could be realised in large courses. There is a widespread perception that core undergraduate engineering courses with large numbers of students are incompatible with design and build projects because too much supervision and extensive shop and construction facilities are required and significant cost are incurred. The six arguments heard most commonly among faculty and administrators when the term "hands-on" is mentioned are: (1) It costs too much;

(2) Our classes are too big to consider any projects which require fabrication; (3) Our machine shops cannot handle the number of students; (4) We don't have enough faculty to staff these activities; (5) Nobody knows how to teach this kind of course; (6) It is impossible or difficult to evaluate design projects which means we can't give students grades. In reality, creating and running a course based on hands-on projects need be no more resource nor staff intensive than a course based on traditional problem sets. And, what a student learns or doesn't learn is reflected just as much in a design and the documentation associated with a design as it is in a problem set. Thus, one of the project goals was to demonstrate that hands-on activities could indeed take place in large, undergraduate engineering courses.

COURSE DESCRIPTION

"Introduction to Engineering" is our new, required, sophomore level design course. The course was built on a foundation of dissection and hands-on design projects designed to teach fundamental principles of mechanical engineering and specific engineering skills. With just over 200 students, it is the largest course in the Department of Mechanical Engineering and as a consequence, provides an example of implementing a hands-on design course for large number of students while making use of minimal university resources and maximising cost efficiency.

A variety of methods were used to keep reasonable limits on teaching staff time while still delivering a hands-on course:

1. Tutorial information was developed and made available on the Web. This is particularly important for a course where basic skills are taught (from Excel to soldering irons), but where students enter with a wide range of backgrounds.
2. Peer evaluation of drawings, designs and projects. Several methods were used including having students exchange their drawing or essay with their neighbour and writing a quick critique on a Post-It note. Another method was to have 10 students come to the front of the class, project their drawing or design on an overhead and have another student critique the work in front of the class. This latter method not only lets the entire class understand how a critique should be done, but also gives those presenting practice in thinking on their feet and speaking informally to a large group of peers.
3. Take home tool-kits (described below).
4. Web-based course administrative procedures. For example, students could access their grades on the Web using a password system for privacy.

As an example of the type of hands-on project that can be done using minimal course resources, early in the course, students formed into teams of four and were given a “Tip-A-Can” assignment. (A project which originated at the University of Rochester.) The task was to make a can tip over, but sometime after students set it upright on a table at the front of the lecture hall and return to their seats, but before the end of lecture. It must also tip without anyone touching the can. One generally sees a wide range of innovative and not-so-innovative solutions to this problem. Most cans were designed using found materials and fabricated at home without needing a shop.

Another quick and inexpensive hands-on project is to have teams of four students construct towers from 100 index cards using only staples for assembly. This project is assigned the first day of class and is due at the second class. It immediately forces students to think about designing to a deadline and to experience working in a team of people whom they most likely do not know but have to get along with sufficiently well to complete the assignment in a hurry.

At the end of the course, students tackle a complex, hands-on design project. They have five weeks to design, construct and test their own microprocessor-controlled robot. The project charge is to "design and construct an autonomous machine that does something interesting for 45 seconds". A few simple rules constrain this open-ended goal. The machine must: (1) fit on a 30 inch by 36 inch base, (2) have at least one moving part, (3) be microprocessor controlled, (4) cost no more than $25 over the components provided, and (5) be safe. Students receive a BASIC Stamp microcontroller board (Parallax Inc., Rocklin CA), three DC motors, a NiCd battery pack and a small assortment of electronic components. The assignment culminates in a public, well-advertised Robot Show where last year 190 working machines filled one of the University's largest meeting spaces, and students had a chance to show off their work to a jury of faculty and representatives from local industry. Events such as these can boost a student’s confidence in their ability to create and provides a window into the excitement of engineering. Many students comment that the robot show was one of the best times in their educational lives and that it committed them to engineering. The show is excellent publicity for not only engineering, but also for the university as a whole, and has been featured in several university public relations publications.

Engineering communication in written, oral and visual forms is an important component of the course. One important goal is to have students become comfortable with a variety of visual communication forms ranging from quick “napkin” sketches to semi-formal

perspective drawings to formal CAD representations of designs. As engineers, students will use all these forms of visual communication, and, as engineers, they will be expected to be comfortable in all forms. In the course, students learn how to create quick perspective sketches as well as Pro/ENGINEER, a popular professional CAD package.

The course has modest instruction and assignments in oral and written communication forms. Each student delivers a five minute oral presentation with overhead slides on an engineering topic of his or her choice. It is the first presentation for most students, but by doing it in a relatively friendly, low-stress atmosphere, fear is reduced. Several formal and informal writing assignments related to the design projects are also given, including e-mail and print forms. Having students write about their designs is an important part of the design learning process.

Throughout the course, the concept of "professional practice" is stressed in the context of assignment deliverables. For example, e-mails with spelling or typographical errors are rejected immediately to reinforce the message that for electronic communication, a different style is required when communicating with a supervisor than when communicating with friends. For the few assignments similar to traditional engineering problem sets, standards were set for presentation and appearance. Hastily executed, hand-written documents were not accepted. By the end of the course, professional appearance and professional practice come naturally to most students.

DISTRIBUTED SHOPS

The load on department fabrication shops and laboratories was minimised through the concept of distributed shops. Activities that traditionally have taken place in central university facilities can just as easily take place in the home, apartment or dormitory room. The robot project was served as a suitable test of the concept. The project could not have been done with 200 students if the students had to construct their machines in the department student shop and programme their microprocessor in the engineering school computer lab. Our solution was to structure the project so that students could succeed using simple construction and code development methods, and then to provide each student with the appropriate tools so that they could develop their robot at home, in much the same manner that they would work on a problem set. Thus the choice of the BASIC Stamp for the control computer because it is simple to understand, simple to programme and can connect to any PC for creating and downloading code.

Each student is provided with the "Introduction to Engineering Equipment Kit" for the duration of the course. The kit is valued at approximately USD 250 and contains a digital voltmeter, an electric power drill, dial calipers for precision measurement, a wire-wrap tool for constructing electronic circuits, several hand tools, the BASIC Stamp microprocessor and software development system, two DC motors and a rechargeable battery. With the kit, students could take apart products and create designs wherever they wished. In addition to the kit, students had the option of purchasing a set of basic hand tools for approximately USD 120, much the same way as they might purchase a required textbook. By providing this resource, projects could now be assigned which assumed access to hand tools, and no student could use the excuse that they didn't have the tools or that the student shop was too crowded. Another advantage of providing and encouraging the use of hand tools is that they are safer than most of the machine tools found in the shop, an important consideration when the majority of our beginning students are novices in the operation of tools. There are financial and logistical challenges associated with purchasing, distributing and maintaining 250 equipment kits, but these can be met with careful planning.

All of the strategies described above were part of the overall mission of lowering the barriers to hands-on design. If it is exceptionally difficult for a student to build, hands-on projects are doomed to failure. By providing easy access to tools, components, and instructions, students can and will spend more time on useful design activities rather than waiting in line for a drill press in the shop. Students really did use their tools to fabricate designs at home which otherwise would not have been possible to construct, and students appreciated the ability to construct at home on their own schedule rather than having to rely on the shop with its limited hours.

Lessons Learned

This project demonstrated that it is possible to create a course which emphasises hands-on activities and to do it in a relatively cost and resource efficient manner. Some of the lessons learned along the way are covered in the sections above. In addition, the following are presented for consideration:

- There will always be resistance by some faculty to hands-on activities. Some criticism is warranted. If the fabrication experience dominates the student's education, students can easily immerse themselves in building their design at the expense of gaining an understanding of what they are doing. It is important that a balance be established between completing the project and becoming familiar with the tools and process that underlie successful design practice. One way of doing this is to tie analysis and design

together in meaningful ways so that students realise designs they have first analysed. We are still working on ways to achieve this ideal.

- Successful hands-on activities can be excellent publicity for the department and university. Our robot project has received extensive press coverage inside and outside the university and has been used by officials to publicise university activities. Although promoting this sort of publicity may be treated with disdain by faculty, in fact it can generate support and protection for hands-on activities. When the president of a university cites your programme as an example of what is exciting in the university, you know that engineering will continue to receive strong support from central administrators.
- Extensive use of the Web as a design information database works. Design necessarily entails information gathering on the part of the designer. To make this easier for novice student designers, gather information, both externally and internally generated, organise it in some reasonable fashion and place it on the Web. Although the time to create and maintain such a database is substantial, it ultimately will save time in student interactions since students will now have easy access to information which they ordinarily would require instructor time to obtain. Plus, today's students expect information to be on the Web and are extremely adept at finding and using it.
- It takes time, energy and dedication to create new courses, even more so if those programmes involve hands-on activities. The rewards come from the bright, energetic students who become excited and motivated by design.

NEW PRODUCT DESIGN AND BUSINESS DEVELOPMENT PROGRAMME

At the graduate level, the University of Minnesota has launched an initiative that creates a novel educational model for teaching the principles of product design and development. The goals of this effort are:

1. To train future leaders of product design and business venture teams.
2. To improve the process of product design and business development through the understanding and development of new product design methodologies and entrepreneurial strategies.
3. To design new products and business opportunities for sponsoring companies.

The programme represents a new partnership between the University and industry to advance the state of product design and business development. This section of the paper describes the

programme, discusses essential issues for university-industry collaboration, and provides examples of projects undertaken.

PROGRAMME DESCRIPTION

New Product Design and Business Development is a graduate level course offered jointly in the Carlson School of Management, the Institute of Technology, and the Department of Biomedical Engineering at the University of Minnesota. The course brings together students, faculty and representatives from client business firms to design and develop new products and business plans. Teams of six to ten students, half second year MBAs and half graduate level engineers, work together for the entire academic year (September to May) to develop a product and business concept. By May, each team is expected to deliver a working physical prototype of the product and an extensive business plan that details production, marketing and financial considerations for the product. Between four and six projects are undertaken each year.

The coaches for the teams include faculty from marketing, operations and entrepreneurial studies within the Carlson School, and from mechanical, electrical and biomedical engineering within the Institute of Technology. Executives, managers and technical personnel from the sponsoring company provide additional coaching. The coaches provide instruction in business creation, product design and product development, and have overall responsibility for seeing that the team sets appropriate, realistic goals and proceeds towards them on a timely schedule.

The project undertaken by the team is selected carefully by the company in consultation with the course faculty to provide an appropriate educational experience for the students, to provide benefit to the company and to ensure the maximum chance for success. The general area of the product should be known, but specific product requirements should not be dictated to enable full exploration of market opportunities by the product development team. The project should have significant marketing challenges associated with it - in contrast to minor product line extensions - because student and faculty skilled in marketing are part of the

team. The project should have significant engineering content - in contrast to clothing, books or paper clips - because skilled student and faculty engineers are part of the team. Mechanical, electronic or electromechanical products, including those with embedded computers, are particularly good choices as are non-implantable medical devices given the expertise in medical device design at the University of Minnesota and the concentration of medical device companies in the Twin Cities area. Often, the best choice is a novel product which the sponsor would like to see developed but is in an area in which the sponsor does not have existing expertise, or is one for which there are insufficient resources to develop the product completely in-house.

Because the design teams work on real projects, issues of confidentiality and intellectual property must be settled well before the projects begin. A standard agreement form was created. Highlights of the agreement are that patent rights are assigned to the company, and that confidentiality is maintained. Assignment of patent rights to the company is essential if the team is to undertake real projects. The confidentiality and intellectual property agreement with each company is signed by all students and faculty in the course, not just those on the project. This facilitates team interaction and enables the faculty and students to generalise what is being learned from each project. We have found sharing information to be one of the best methods for learning about and improving the product development process, and the company has the benefit of many more students and faculty thinking about their product.

Sponsoring companies pay a project fee of USD 25,000 to partially offset the instructional costs associated with the course. Independent firms with total revenues of less than USD one million per year pay a reduced fee of USD 10,000. In addition to the project fee, the design team incurs project costs to conduct marketing surveys, hold focus groups, construct prototypes and produce reports. Each team is also provided with a small discretionary fund out of the course budget to cover expenses that are course, but not project related, or for small purchases that are needed immediately and would take too long to clear company purchasing channels.

The deliverables at the end of the nine months include one or more working prototypes, a detailed engineering report and a comprehensive business plan. Although the students are expected to perform at a level that will result in substantial benefit to the company, no guarantees can be made, and the company must have reasonable expectations about outcome. It is important to realise the main purpose of the course is to provide an appropriate educational experience to the student rather than a direct service to the company.

PROGRAMME FEATURES

There are several features of the programme which make it somewhat unusual and help contribute to its success. One of the most important is that the projects are real. Projects are taken on only if the company has committed to manufacture the future product. This should be contrasted with our undergraduate design course that also runs industry sponsored projects, but typically the company does not as closely watch the results of those projects.

The mix of engineering and business students is a major highlight. Projects are run with true cross-functional teams and the engineers are encouraged to take on marketing tasks and vice-versa. As faculty, we are rewarded when we see a business student sketching ideas in a brainstorming session or making a part on the lathe in the Mechanical Engineering student shop, or to see an engineering student conduct a customer interview or run some profit forecasts on a financial spreadsheet. We do not expect engineers to become expert marketers or marking students to become engineers, but for success in product development, each team must learn from the other.

The interaction with the company is substantial. Two or more company representatives from marketing and/or engineering attend the weekly team meetings held on campus. Companies have spent thousands of dollars fabricating prototypes or supporting professionally moderated focus groups, all part of normal product development costs. In many projects, students spend considerable time at the company, particularly in the final weeks. Towards the end, as the project is gradually handed off to the company, more and more work is done by company staff working alongside the students. Final presentations held at the company site have drawn

up to 20 company representatives, including CEOs and VPs. This is convincing evidence that the company cares about the result of the project.

The confidentiality and intellectual property agreement is the key that enables the university to participate in real projects with companies. Settling on a form for the agreement required substantial negotiations between lawyers for the companies and those for the university. Universities have no hold over student work done for courses, but it is unusual for the university to allow a contract where faculty assign their rights to a company since faculty are employees of the university. Nevertheless, all parties agreed that this was necessary to enable a substantial learning experience for the students.

The revenue from company participation fees supports some of the instructional costs of the programme, which admittedly is faculty intensive. The remainder of the fees has been used to support and augment the design infrastructure. For example, we paid for part of a rapid prototyping machine and purchased a number of equipment kits for the undergraduate introduction to engineering course from programme revenues.

PROJECTS

New Product Design and Business Development started in the 1994-1995 school year. By the end of 98-99 we had completed 25 projects, and over 150 graduate students from business and engineering have participated along with eight faculty. We have worked with small startup companies such as Soil Sensors which has five employees and makes a soil moisture sensor for precision farming, and with companies as large as 3M with thousands of employees. Products have ranged from a smart clutch-brake system for Horton Manufacturing to a controlled-motion electronic integrated circuit testing machine for Aetrium Inc. to a micro-endoscope for Micro-Medical Devices. Several patents resulting from project inventions are being filed and many working prototypes have been developed.

In 1997-98, the 3M Post-it Flag group approached the university to work on a project. The challenge was to find new, innovative products for Flags that could increase sales, possibly

by opening new markets. The team of students, faculty and 3M representatives generated approximately 200 concept ideas at the level of index card sketches, built about 40 prototypes and narrowed selections down to four or five final ideas realised in refined prototypes. Along the way, voice-of-the-customer information was gathered through dozens of one-on-one interviews and four professionally moderated focus groups. Sales forecasts were sufficiently encouraging that 3M will soon go forward with a placement study now that the project has been fully handed over to the 3M team.

In another project, a team working with Augustine Medical, a medium size medical device company specialising in products that keep patients warm during surgery, examined new markets for the company's core technology. That new market was identified and clearly defined in the final business plan, and several prototypes built and trial tested in the field. Augustine Medical officials stated that working with the team saved them 1-1/2 years in the product development cycle.

Another recent project was conducted with Sulzer Medica, a Swiss Company that is the leading European manufacturer of joint implants. The project entailed developing a new product to facilitate hip surgery. Having a sponsor several thousand miles distant highlighted the advantages and disadvantages of e-mail, fax, phone and video-conferencing communication media, all of which were used. To further complicate matters, the product is intended to be introduced in Europe first, but it was difficult to gather voice-of-the-customer data from European orthopedic surgeons because of the distance. Nevertheless, the team took some risks and developed a working prototype that Sulzer will take on to manufacture, and a detailed business plan covering the product introduction in both European and American markets.

Lessons Learned

New Product Design and Business Development has been successful in all three of its objectives. First, business and engineering product development leaders have been trained because students experience the full product development cycle in a realistic setting. Many of

our graduates have gone on to product development positions in companies. Second, research results are just starting to be generated from the product development process studies conducted in parallel with the projects. Third, companies are benefiting from the creation of real product prototypes and real business plans.

Along the way, we learned several lessons that might be of interest for those considering similar programmes:

- Engineering and business must lead the programme equally. Ours is not a programme out of the engineering school with a business component added, nor a programme out of the business school with some engineering added, but rather is led by both schools. This has two advantages. First, a total development process can be followed, rather than just marketing or just engineering. Second, faculty and students can learn from their new colleagues who are nominally in different areas, but who can find common ground in new product development process.
- Creating appropriate confidentiality and intellectual property policies and agreements takes time and requires considerable negotiation between company and university lawyers. Faculty and company product managers must stay in the loop to make sure the final agreement makes good sense. Once an agreement has been reached with one company, use it for all companies since multiple agreement forms or allowing companies to modify agreements just leads to endless rounds of negotiations.
- The formal academic component of the course should centre on learning a product development process. This is what differentiates the course from a work-study programme or company internship that does not require formal academics. Through targeted lectures and readings, we advocate a total development process, from needs identification through product launch and beyond. By absorbing the didactic instruction and by observing all teams working, students can generalise beyond their own specific projects to deepen their understanding of product development process.
- The closer geographically the company is to the university, the greater will be the company interaction. We have worked with many companies in the Twin Cities area and most participate fully. Projects whose sponsors are in different parts of the country or in

different countries tend to evolve into an "over-the-wall" format where the company hears about results at a final presentation rather than being a part of the team during the development process.

REFERNCES

- www.me.umn.edu - The Department of Mechanical Engineering at the University of Minnesota
- www.me.umn.edu/courses/me2011 - The Introduction to Engineering course
- www.npdbd.umn.eduThe New Product Design and Business Development Programme

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