A Hands-On "Introduction to Engineering" Course For Large Numbers of Students

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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 mechanical engineering students and which could also serve as a model for design education at large state universities. The major outcome was the creation of a core lower division course, Introduction to Engineering, which now has an enrollment of just under 200 students per year. The course has a hands-on approach and students learn engineering fundamentals and specific engineering skills through a series of dissection and design assignments. Resources were developed to allow students to fabricate their design projects at home and to use the Web rather than course staff as a first source of information and guidance. In this way cost and teaching staff for the course were minimized. The course has completed its third year and has gathered anecdotal evidence of success.

I. Introduction

The goal of this project 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 were interested in returning a hands-on design component to engineering education and having design be a unifying theme throughout the student's undergraduate program. This was in contrast to our old program where design was a subject tacked on at the end with the view that a student was not qualified to do design until the fundamentals of engineering were mastered.

A particular objective of this work was to demonstrate that hands-on projects could be realized in large courses. There is a widespread perception that core undergraduate 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. Because experiential design should be an integral part of any engineering curriculum, our experiences may server as an example for others wishing to take the same path.

II. Background and Origins

This project must be viewed in the context of current engineering education practice. Engineering design is widely recognized as a critical component of any undergraduate engineering curriculum. Recently there has been considerable debate on what and how to teach design. The debate is fueled by the perception that methods of teaching design which may have worked in the past are 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 has also become increasingly uncomfortable with how designers are being educated. Leaders in industry are calling 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.

Most engineering schools have realized the need for a new model of design education which stresses not only technical competence, but also provides training in communication, management and the complete product design cycle, as well as a number of practical, creative design experiences. Many schools have implemented new courses and programs which include these experiences. Large state universities, however, have specific characteristics which require special attention. These include: (1) large numbers of students, (2) students entering with a wide diversity of backgrounds, abilities, ages and learning styles, and (3) large numbers of transfer students coming from public two-year community colleges and four-year non-specialty colleges. Programs that work in small private universities often do not scale well to large public universities.

As our project progressed, the faculty realized that one of the most important contributions we could make would be in understanding how hands-on design courses which entail fabrication, prototyping and testing could be taught to large numbers of beginning engineering students in a cost- and resource-efficient manner. The six arguments heard most commonly among faculty and administrators when the term “hands-on” is mentioned are as follows: (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) I don’t know 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 didn’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.

III. Course Description

“Introduction to Engineering I & II” (ME1010/12) is a new, required two-quarter lower division 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. It was taught as a pilot for 24 students in 1995-96 then became part of the required curriculum the following year when enrollment climbed to 105, and to 190 the year after that. It is now 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 maximizing cost efficiency.

Scaling up from 24 to first 105 and then 190 presented an interesting challenge, particularly when the unwavering objective was to maintain a hands-on flavor. 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 neighbor and writing a quick critique on a Post-It note. Another method was to have ten 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 which 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 autonomous, 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. The show is well attended and has good media coverage including occasional spots on the television news. 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 also excellent publicity for not only engineering, but 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. Teaching CAD is relatively straight forward. Pro/ENGINEER, a popular professional CAD package, is used in the course. The major obstacle to overcome was that Pro/E is a complex package that takes time to learn well, but since Introduction to Engineering is not a CAD course, only a limited amount of class and assignment time could be devoted to CAD instruction. Further, most CAD and graphics textbooks assume a full, 13 week graphics course and have too much detail for our needs. The solution was to create a series of targeted CAD assignments backed up by substantial tutorial information on the Web. The most complex CAD assignment was to construct a detailed solid model and working drawings of a standard BIC Classic ball point pen which was provided to each student. The pen is a simple enough shape that most students could complete the assignment but has sufficient detail and nuances that advanced students could pursue the assignment in depth.

Quick perspective sketching is equally important as a means for engineers to communicate their ideas. Here one must overcome the cultural resistance to drawing, the attitude of “I can’t draw” and “Drawing is for artists”. Students received base-level training in sketching, constant repetition of the “anyone can draw” and “engineers must draw” themes, and were instilled with the principle that engineers need not be professional artists but simply sufficiently proficient to communicate their ideas. The results were striking and confirmed that indeed most students are quite competent at visual communication if given purpose and opportunity.

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. For example, in the Tip-A-Can project, students must think about the form of energy storage and energy release mechanism used, the two engineering fundamentals which drive that project. In the very first tower building project, they write about their early experience with the design process: how ideas were created and selected, how it was to work in a team of people whom they did not initially know, and how it was to work towards a strict deadline with neither extensions nor excuses possible.

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 “boss” 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.

IV. Distributed Shops

The load on department fabrication shops and laboratories was minimized through the concept of distributed shops. Activities which 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 an excellent 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 program their microprocessor in the engineering school computer lab. Neither facility has the capacity nor supervision to handle such numbers. 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 program and can connect to any PC for creating and downloading code.

Students who did not have access to hand tools at home had the option of purchasing a complete kit of tools (purchase price approximately $60), in much the same way 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.

Some tools and components are too expensive to expect students to purchase, so each student was also provided with a loaner kit that contained a digital voltmeter, an electric power drill, dial calipers for precision measurement, and a wire-wrap tool for constructing electronic circuits. The loaner kit also contained components for use in the robot project, including the BASIC Stamp microprocessor board, manual and software development system, one DC gear motor, one small

DC motor, and a 12V NiCd battery pack with recharger. The total value of each loaner kit was about $250.

For the robot project, each student received a small set of electronic components, including several power transistors, some resistors, LED's, and wire. Because the cost of these components was low and the logistics of handling returns too complex, the set was given to each student. Because many students required additional electronic components over and above what was provided, and because purchase of components in small quantities is expensive and logistically complex for students without transportation, a small "Robot Store" was created which sold a limited selection of components to students at cost.

All of the strategies described above (toolkit purchase, loaner kit, component sets and store) 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.

There were many lessons learned from selling toolkits, providing loaner kits, and setting up a store. The experience brought the course staff a little closer to retail shop management than we wanted, but an infrastructure for these operations was eventually created which was neither overly burdensome to course staff nor overly expensive. The following list describes some of what was learned:

1. A source of capital funding is required to purchase the loaner kits. We own approximately 200 kits valued at $250 each for a total capital cost of $50,000. The funds came from (1) a Department of Education Fund for the Improvement of Postsecondary Education (FIPSE) project grant, (2) an instructional equipment grant from the School of Engineering, (3) a special Department of Mechanical Engineering fund for special initiatives, (4) an academic initiatives grant from the Coca-Cola company, (5) funds generated from companies participating in our graduate New Product Design and Development Program and (6) general department funds. This was indeed a wide range of sources, but the money was relatively easy to obtain. The concept of providing equipment and components to undergraduate engineering students so they can participate in more hands-on activities resonates well with organizations which support academic initiatives.

2. Purchase quality components for loaner kits. For example, during the pilot version of ME1010, the loaner kits included cheap ($18) digital voltmeters because of the desire to save money. Many of the meters had problems from the start, and many more were returned broken. Having learned our lesson, first-quality, industrial-strength voltmeters from a well-known instrumentation company are now used.

3. Have a written contract which students sign when they receive their kit. The contract used in ME1010 states that the student received a kit and that he or she will receive an 'F' for the course if the kit is not returned or if missing or broken parts are not paid for. The cost of each component is listed on the contract so that the value of the kit is clear from the start. An accounting system was established where money paid by students for missing equipment can be returned to the fund which purchased the equipment.

4. Create an efficient system for distribution and return of loaner equipment. With 200 students and multiple components per kit, keeping track can be a nightmare. Distribute and return as kits rather than as separate components. Have one or two time periods for distribution and return to

avoid having to staff multiple sessions. Minimize handling time per kit so that lines of students move quickly.

5. Have a resource and source of funds for equipment repair and replacement. We hire undergraduate students on an hourly basis to inventory and repair components as needed. Approximately 5 per cent of our inventory must be re-purchased each year to replace missing or broken equipment.

6. Establish an agreement with a large local home center or hardware store for student purchase of hand tool kits. Make it easy for students to purchase directly from the store. In our first year of teaching the course, the department purchased the kits from the store and then sold kits to students. It turned out to be chaotic as the kits were not stocked properly by the store, too many were ordered, there was no place to store the kits between time of purchase and selling them to students, and the department accounting system had no appropriate means for handling this kind of financial transaction. Having learned that lesson, the department now only act as an agent for the store. Orders for toolkits are placed on behalf of the students and delivery is arranged so the student does not have to travel to the store. All payments and accounting are done directly between the student and the store, not through the university. The course staff still specifies what is in the standard kit and arranges with the store to provide a discount to the students because the kits are purchased in quantity.

7. On-campus "stores" for design projects should stock a limited number of inexpensive items, accept cash payments only, limit purchase quantities, and have all prices in multiples of $0.25. The Robot Store stocks power transistors, LED's, wrap wire, relays and three values of resistors. These are the components which students use most and are hard for students to purchase on their own. Some modest form of inventory control is useful to prevent running out of a key component just before a project is due, or ending up with too many leftovers after the course is complete. Have fixed hours for the store so that staffing isn't a problem. Put all information about store operation and store contents on the Web and if any student comes by with obvious questions, send him or her back to the Web. The Robot Store is staffed by the course secretary and store hours are limited to every other day for two hours. Since there isn't much traffic, adding the role of store manager was not an excessive burden on the secretary.

V. Other Activities Connected with the Course

The Web was used heavily as an information database. Sites were developed to support design projects and design courses (including an on-line grades system), and a designer’s resource site was developed for the department. The Web is a powerful way for students to gather information without requiring help from a course instructor and thus increases teaching efficiency in large courses.

Links were formed to two institutions in the Minnesota higher education system. One undergraduate course at the University of Minnesota Duluth was modified to include experiences similar to our course and Century Community College developed a new course modeled after ours. The goal of these coordinated efforts was to make it simpler for students who wished to transfer from those institutions to the University.

Classroom assessment, focus groups and surveys were used to gauge student reactions to the new core course and to determine if taking the course had any impact on students views of their education. Grades and enrollment data were analyzed to determine if the course had an impact on students grades at graduation or on retention rates. Reactions to the course were generally favorable. The course is still too new to determine if it has had any statistically significant effect on graduating students' opinions of engineering, their grades or on retention.

VI. Conclusions and Lessons Learned

This project demonstrated that it is possible to create a course which emphasizes 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 by practitioners who may be interested in implementing similar courses:

- 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 realize designs they have first analyzed. 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 publicize 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 program 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 makes sense. 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, organize 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 programs involve hands-on activities. The rewards come from the bright, energetic students who become excited and motivated by design.

VII. Additional Information

Additional information on Introduction to Engineering I & II, including syllabus, assignments and project descriptions, can be found on the Web at `www.me.umn.edu/courses/me1010/`.

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