ENGINEERS INVENT AND INNOVATE

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Abstract *¾ First-year students at CU gain a hands-on introduction to engineering through a design and build projects course. In fall 1998, a course with an emphasis on entrepreneurship was piloted to provide advanced and transfer students with similar hands-on opportunities. This paper summarizes course components and lessons learned, and describes some of the products invented.*

Students design and build an invention of their choice, and explore entrepreneurial topics including profitability, marketing, raising venture capital, angel investors and patenting. Creating mini-business plans forces teams to estimate the manufacturing cost of their product and forecast potential sales revenues. A two-week introductory design project provides an early opportunity for creativity, as well as insight into individual strengths and weaknesses in a team environment. Assessment results are presented, as learned from student focus group interviews and pre- and post-course innovation skills assessment surveys.

In spring 2000, two student teams received funding from NCIIA to continue development of their products.

Index Terms ¾ engineers as entrepreneurs, innovation, invention.

INTRODUCTION

Since 1994, CU students have experienced a hands-on introduction to engineering through projects designed and built by interdisciplinary teams in the First-Year Engineering Projects Course [1, 2]. This successful College-wide course is now offered to approximately 360 students annually. The course is tailored to typical first-year students. However, many students either transfer into engineering later in their academic careers, or delay taking the course, for a variety of reasons.

A need was identified for a design course tailored to more mature students who would still benefit from a hands-on introduction to engineering. The new course would feature an area that was otherwise lacking in our curriculum—product invention and innovation—including various aspects of entrepreneurship. The course was piloted in 1998 [3]. This paper focuses on the refined course offered in fall 1999.

COURSE COMPONENTS

Product Brainstorm

With a course focus on invention and innovation, a brainstorming session was held during the first week of class to generate potential product ideas and introduce students to this important creativity tool. The objective was to develop a list of products that the students would subsequently design and build. Therefore, the products had to be feasible for a one-semester course and engage student interest. Individual student voting narrowed the large initial list to a small roster of potential products. Instructors exercised veto powers to eliminate projects that were too large in scope.

Team Formation and Management

A significant course goal was for students to have a successful team experience. To that end, several factors were considered during the team formation process:

- Individual product preferences from the list generated by the brainstorming process
- A skills assessment survey identifying individual strengths in areas such as hands-on and computer-aided design experience, analytical expertise, etc.
- Instructor observation of individual social and communication styles
- Gender - when possible, women students were paired together to minimize their potential for being dominated in predominantly male teams

Based on this information, the instructors assigned students to five-member teams for the entire semester. Throughout the term, the instructors continuously coached the teams. At weekly team meetings, team effectiveness was one topic of discussion. And, teams were expected to include honest assessments of their team effectiveness at each of four class presentations. Mid-semester, each team wrote a candid evaluation describing individual contributions and areas in which improvement was needed. Students typically found this soul-searching difficult and uncomfortable, yet later commented on its value. As needed, instructors met with individual students to discuss ways to improve their team contributions. The instructors continuously reinforced the concept that the overall objective was team success.

Mini-Design and Creativity Project

To kickoff the course, the newly formed teams embarked on a two-week mini-design challenge. Patterned after the

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[3] Acknowledgment: This course was developed with support from the NCIIA.

design project used by Faste and Roth of Stanford University in their creativity workshops for engineering educators, the task was to design and build a model of an amusement park ride with a motion picture theme [4]. Materials were limited (primarily foam core, glue and pins) and time was short.

In this exercise, students learned much about how their team functioned under pressure. Peer evaluations coupled with instructor observation provided insights about individuals' contributions to team success early in the course. The instructors met one-on-one with each student to discuss their performance in this initial team challenge. This process helped to shape teams that could function reasonably well before launching the major design phase of the course. When presentation day arrived, students were enthusiastic and proud of their creations (Figure 1).

FIGURE 1.
STUDENTS CELEBRATE THEIR SUCCESSFUL MINI-DESIGN PROJECT.

The Main Event

The remainder of the semester focused on designing, building and testing the chosen products:

- A device to haul heavy gear up rock faces during long climbs (Figure 2)
- A remotely actuated bicycle lock
- A system to tell rural dwellers they have mail
- A commuter bicycle cup
- A one-touch switch to adjust the volume of portable music players for skiers or people with disabilities

Teams used the four hours of weekly studio time to evolve through the phases of product design, including defining design requirements, generating alternative design concepts, exploring various decision methods to select a concept, using appropriate engineering analysis to guide design decisions, fabrication, testing and iteration. Each student kept a design journal. Periodic design reviews honed oral presentation skills and kept the entire class informed of progress.

The course was held in a design studio in the Integrated Teaching and Learning Laboratory (ITLL) [5]. The design studio provided group work areas, workbenches with small hand and power tools, "smart" projection capability, storage space and one computer for each team (offering SolidWorks® CAD modeling software, see Figure 3). Available resources included a CAD/CAM teaching assistant, and an in-class undergraduate teaching assistant. In addition, students had access to the state-of-the-art fabrication capability of the ITLL, allowing them to realize their dreams. The Manufacturing Center includes two CNC milling machines, a CNC lathe, a CNC laser cutter, conventional machine tools and a rapid prototyping system. The Electronics Center features fabrication, measurement and testing equipment. Both facilities are professionally staffed.

FIGURE 2.
TEAM WALL HAUL DEMONSTRATES THEIR UNIQUE ROCK CLIMBING HAULING SYSTEM.

At the end of the semester, students showcased their functioning products at the College-wide Design Expo, open to the public.

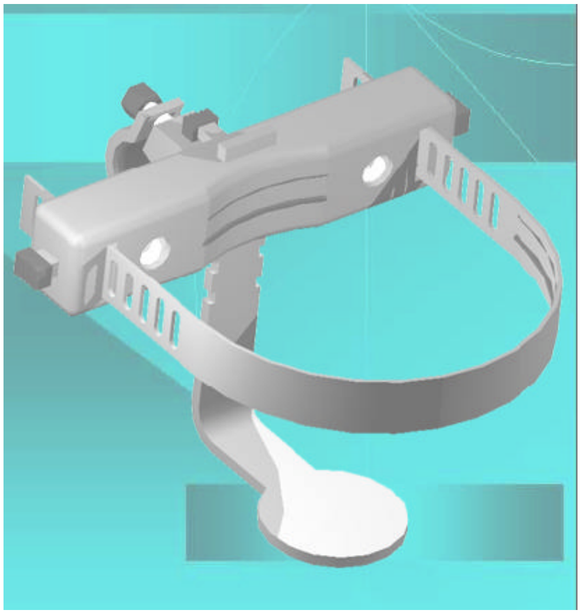

FIGURE 3.
CAD MODEL OF THE COMMUTER BICYCLE CUP.

Entrepreneurship

A major course objective was to determine whether each project could succeed financially. A series of guest lectures by an entrepreneurship professor introduced the engineering students to the world of the entrepreneur. Topics included characteristics of entrepreneurs, sources of financing, and profitability and marketing considerations. A guest "angel" shared his views on what convinces him to invest money in new ventures, and another lecturer explored patenting and intellectual property issues. An engineering faculty member helped students estimate the manufacturing costs of their designs, which were factored into the profitability equation. Finally, two successful inventors shared their experiences and passion with the class.

Each team prepared a written business plan and presented it orally. Many teams conducted market surveys to gauge potential sales volumes, as well as what consumers might pay for the new products. Patent searches on the Internet revealed the extent of competition.

An interesting experiment in distance teaming was tried, with limited success. Most engineering students are unfamiliar with the business world. Similarly, many business students have little exposure to the "real" world of product development. On the assumption that both students groups could benefit from interaction, each of our student teams was paired with a team of business students in a business plan class at a distant university. The hope was that CU engineering students would benefit by having "experts" from the business discipline developing a parallel business plan for the product they were developing, while remote business plan students would benefit from having a tangible product under development as the focus of their own business plans. However, after initial contacts via e-mail, little interaction occurred. CU students, deep into the intensive stage of product development and iteration, and preoccupied with developing their own business plans, viewed the distance teaming as a burden, instead of a benefit.

NCIIA Proposals

Written communication is an important skill for budding entrepreneurs. To provide experience in writing for fund raising, each team wrote an E-Team proposal to the National Collegiate Inventors and Innovators Alliance (NCIIA) requesting up to $20K in continued funding. After the course ended, each team was asked if they wanted to continue product development. Two of the five teams opted to proceed and worked with the instructors to polish their proposals for submission to NCIIA. Both teams were successful and will continue to work during the summer to iterate their designs and explore patent possibilities.

EVALUATION

Team Component

Modeling the professional world in which the finished product matters most, 70% of each student's course grade was based on team performance. Factors included the mini-design project, oral design reviews, overall product quality (including how well it met design requirements), thoroughness of the business plan, a user's manual, NCIIA proposal and the effectiveness of the Design Expo poster.

Individual Component

The remaining 30% of each student's grade was based on individual contributions to team success. One way to assess this is through peer evaluation, conducted immediately after the mini-design project, and at the end of the semester. Each student divided a hypothetical $1,000 bonus among all team members (including him/herself) accompanied by a rationale for the distribution. Averaged results usually gave a clear picture of each team's high and low achievers. Typically, low achievers rate their own contributions as lower than their teammates', although they usually do not rank themselves as low as their peers do. In addition, the instructors contributed their own evaluation of each individual's performance.

Student Portfolios

A portfolio is a powerful tool for assessing how effectively students integrate various concepts and course experiences. Additionally, it provides students with coherent documentation of their work, which can contribute to their sense of accomplishment. Having a concise, well-organized description of their successful products can be valuable for internship and employment interviews as well. On the other hand, the inclusion of portfolios demands a great amount of work for both the student and instructor.

Based on lessons learned from the pilot offering of the course [3], portfolio requirements were scaled back to make them less of a burden on both students and faculty. Each portfolio included team documents that were generated during the semester, such as printouts of presentation slides, the user's manual, etc. The main individual component was an in-depth reflection of each student's experience with the design process. However, the students viewed having this additional requirement due at the end of the term, coincident with the end-of-semester deadline to assure a functioning product, as too onerous.

ASSESSMENT

Faculty Course Questionnaire

One assessment tool routinely administered at CU is the Faculty Course Questionnaire (FCQ), an end-of-semester survey of student perceptions. For this course, the standard FCQ format was augmented with specific questions that addressed how well the course learning goals had been achieved.

Students rated this course overall as a "B." In examining the individual responses, it appears that the biggest negative factor was workload, which students rated at 7.9 on a 10-point scale (5 = "OK"). Students clearly enjoyed the design and build aspects of the course, but found that the writing assignments distracted them from that focus.

Student Focus Group Interview

In addition to the FCQ, a *class interview* was conducted to solicit in-depth feedback (see [3] for details). The majority of the class agreed that the course's strong points were:

- Hands-on design process
- Being able to choose the product to invent
- Presentation experience
- Showcasing their product at the public Design Expo
- Quality of the resources available for product design and fabrication
- Technical support provided

Suggestions for improvements included:

- Eliminate distance teaming component.
- Give more credit, or reduce the workload.
- Require *either* a business concept presentation or a written business plan, not both.
- Scale back portfolio requirements, especially at the end of the course when everything else is due.

Innovation Skills Assessment Surveys

Since a major course intent was to improve students' innovation skills, a 31-point self-assessment survey was administered at the beginning and end of the course. As seen in Figure 4, most of the topic areas surveyed increased during the course. The following changes were statistically significant:

- Appreciation of iteration in the design process
- Ability to define functional requirements to meet design objectives
- Ability to generate alternative design options
- Creation of physical models of alternative concepts
- Delivering a project within budget
- Use of engineering analysis to drive design decisions
- Use of technology for effective presentations
- Producing effective posters
- Knowledge of the patent process
- Knowledge of business issues in design

LESSONS LEARNED

The design of a course parallels the design of a product: it gets better with critical feedback and iteration. Some *lessons learned* that will be applied to the next offering of the course are:

- Adjust the course requirements so that students can focus on completing their products during the intense time at the end of the semester.
- Retain the use of portfolios as an organized, coherent record of students' work, but make it a cumulative record that progressively builds during the semester.
- Replace guest lecturers with course instructors for topics such as profitability, marketing and financing.
- Keep the Manufacturing Center open for extended hours as projects become due.

CONCLUSION

One of the underlying philosophies of the ITL Program is that "engineering is about creating things that benefit society." Coupling hands-on product realization with real-world considerations such as manufacturability and profitability is an excellent way to underscore this point.

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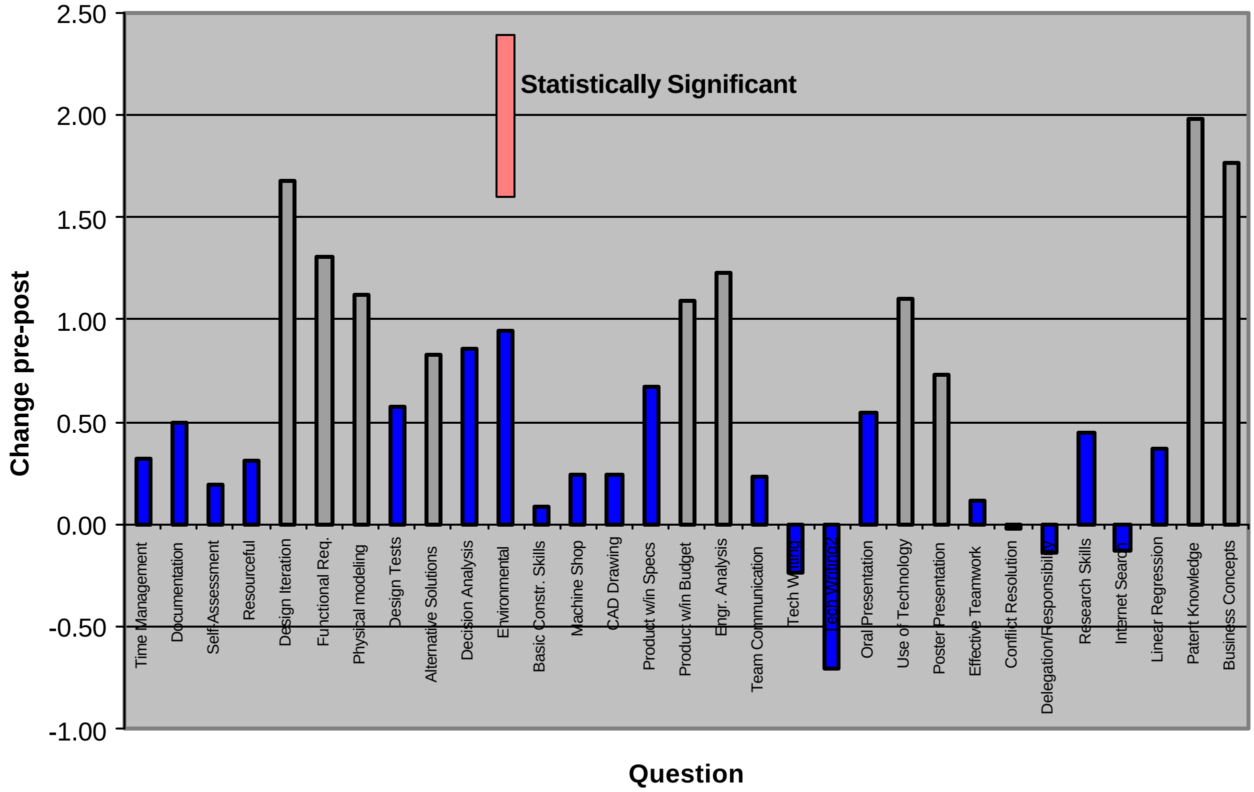

FIGURE 4.
SKILL EVALUATION SURVEY RESULTS