Engineers as Entrepreneurs: Invention and Innovation in Design and Build Courses

Lawrence Carlson, Jacquelyn Sullivan, Susan Poole and Melinda Piket-May
Integrated Teaching and Learning Program
College of Engineering and Applied Science, University of Colorado at Boulder
Boulder, CO 80309-0522

Abstract - *For several years, first-year engineering students at CU have experienced the joys and frustrations of engineering in a College-wide introductory design-build-test course. The course introduces students to engineering through hands-on, open-ended team design projects. The course is intended to serve the needs of entry-level first-year students, who are of similar age and maturity. With support from an NCIIA grant, a new course targeted at advanced and transfer students, and with an emphasis on entrepreneurship, was piloted. This paper discusses various elements of both courses as they apply to the process of invention and innovation, describes some design projects, and summarizes the lessons learned.*

Design and Build Engineering Courses

Many engineering students are attracted to engineering because they want to design and build things. Like many other institutions, CU has come to appreciate the value of encouraging first year students to tackle open-ended design challenges, rather than encountering only large lecture-based core classes. Since 1994, engineering students at CU have experienced a hands-on introduction to engineering through completing a series of projects designed and built by interdisciplinary teams in the First-Year Engineering Projects Course [1].

This College-wide course continues to evolve; it is now required in two majors and accepted toward graduation in all others. Twelve or more sections of 30 students each are offered each year. While each section follows a similar format, the nature of the major design project varies between sections. Many design projects have real-world clients, which usually results in the students being more accountable and producing higher quality products. Project themes include assistive technology devices for clients with disabilities [2] and interactive learning exhibits for youth museums and K-12 classrooms.

One student team from the fall 1998 course was successful in obtaining E-team funding from the National Collegiate Inventors and Innovators Alliance (NCIIA) for continuing to develop and potentially to market a unique swing. A blind child with other complicating disabilities, can manually power this swing, providing both entertainment and self-directed exercise (Figure 1).

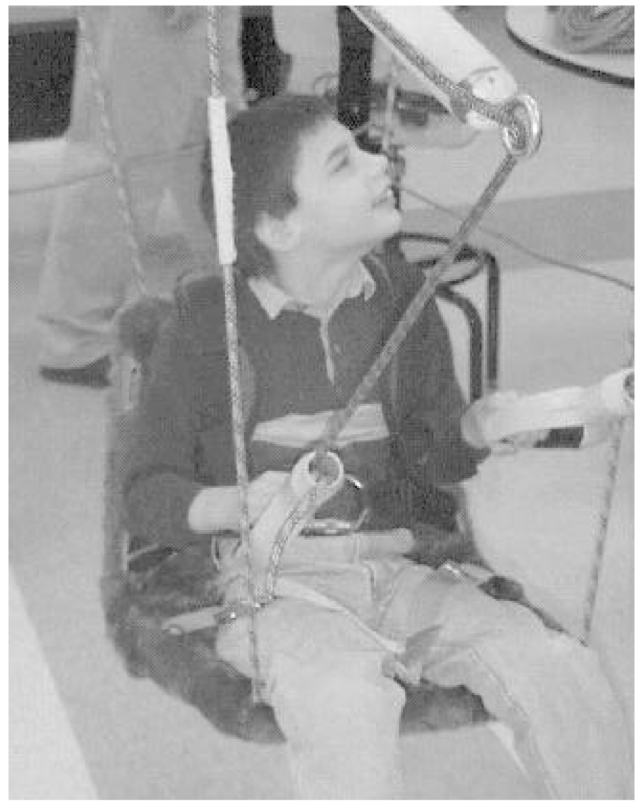

Figure 1. Manually-powered swing for a blind child with other disabilities. Devin loves to be outside, but lacks balance and coordination, and cannot use his legs to pump a swing. With this invention, he can use his strong arms to power the swing, and can get in and out of the swing on his own.

A New Invention and Innovation Course

Some components of the first-year course are intended to aid the development of interpersonal skills to facilitate working effectively in teams, and are tailored to the needs of entry-level students, most of comparable age and maturity level. However, experience has shown that older, non-traditional students, many of whom transfer into the College at the sophomore level or above, do not thrive in an environment that is dominated by younger students.

In order to meet their needs, a new course with an invention and innovation thrust was piloted in fall 1998 and refined for fall 1999. Many of the course goals are similar to those for the first-year course:

- Introduction to engineering as a career
- Experience with interdisciplinary teamwork
- Open-ended, hands-on design experience
- Communication skills (oral and written)
- Experience in keeping a project journal
- Introduction to engineering analysis and methodology e.g., CAD, spreadsheets, measurements, etc.

In addition, the new course was developed to meet the needs of advanced first-year and transfer students, and to focus on developing potentially viable products for the marketplace.

The diversity of students attracted to this course was tremendous, ranging from a very mature 17-year-old woman with 24 hours of advanced placement credit to a man in his thirties with an MBA degree. In addition to a wide variety of engineering majors, several arts and science students contributed to the invention teams.

Course Format

Both courses use a format that reflects the three hours of credit for the course and provides students ample time for hands-on group work on projects. One hour per week is designated as lecture and/or class discussion time, during which students expect to convene for discussions about the design process, hear guest lectures, etc. There are also two laboratory periods per week, each two hours in length. Oral team presentations are given during this time, but many lab periods are left open to allow students time to work on their projects. While it was important to provide students adequate time for hands-on work, it was observed that students tended to use this time less effectively than they could. Methods to enhance the productivity of this valuable time, such as short, hands-on creativity exercises, encourage prompt attendance and quickly get teams to effectively function as a unit.

Short weekly meetings are held between the teaching staff and each project team. The team is expected to prepare for each meeting with an agenda that lists what they have accomplished since the previous meeting, what they intend to achieve during the coming week, any questions, and a reflection on how well their team is functioning. The instructors use this process to promote team communication and accountability.

Project Selection

Although provided a list of possible design projects from which to choose, students in the pilot course preferred to select their own projects. Teams are formed based on self-assessed social styles, combined with the instructors' judgment of distribution of critical skills and optimum groups (taking into consideration gender distribution, etc). Each team must reach consensus on project selection. In the second course offering, students will generate project ideas through brainstorming, and project preference will be factored into team formation. Design projects from the pilot offering included a folding toothbrush designed for people wearing braces, a radio controlled toy snake, a system to visualize fluid flow in an interactive museum exhibit and a working demonstration of hydroelectric power generation.

Focus on Entrepreneurship

Lectures, frequently employing an active learning format, sharpened the entrepreneurship focus of the course and supported the team tasks and assignments. Guest lecture topics included aspects of entrepreneurship, raising venture capital, case studies of successful entrepreneurs, intellectual property, the patent process, and case studies by innovative local inventors showcasing their inventions. Students were also exposed to the various phases of the design process and participated in creativity exercises. All students in the class signed non-disclosure agreements to protect their classmates' intellectual property rights and conducted patent searches via various Internet sites. One team was astounded to find more than 700 patents covering toothbrushes, but relieved to find that their design infringed on none of them.

Resources to Support Invention

The class was held in one of the first-year design studios in the new Integrated Teaching and Learning Laboratory (ITLL) [3]. The design studios feature group work areas, work benches with small hand and power tools, "smart" projection capability and one computer for each team, which included SolidWorks CAD modeling software. Like the first-year course, two undergraduate teaching assistants provided guidance and support. 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 new fabrication, measurement and testing equipment. Both facilities are professionally staffed.

Emphasis on Communication Skills

The importance of communication was emphasized throughout the course. Students shared the progress of their projects through various team oral presentations, including preliminary, critical and final design reviews. Presentations were evaluated by the teaching staff and by peer consensus. Each team discussed every presentation and submitted a consensus evaluation. One required element of each presentation was a candid reflection on the team's effectiveness as a working group. Each team exhibited their creation at a public and judged Design Expo, accompanied by an informative poster.

Quality writing was also emphasized. Students created individual portfolios summarizing their semester's experiences and learning, including individual essays integrating the various components of the design process as it applied to their projects. Each student was required to keep a bound inventor's journal documenting her/his creative work. The journal was checked periodically and commented on by the teaching staff - but not graded. Consistent with experience from the first-year projects course, students resisted writing assignments, which the instructors concluded reinforces the need to emphasize, and practice, written communication.

Evaluation and Assessment

Evaluation and assessment in this course occurred on several levels. One focus of assessment was, of course, student learning and performance. A second focus was the course itself, including the content and the teaching staff (instructors and teaching assistants).

Evaluation of student performance was multi-dimensional, and included both group and individual components. The group component accounted for 60% of a student's total grade. All members of a team received the same grade for the group components, such as: design presentations, quality of the final product, poster effectiveness, and a written operations manual or advertising materials to support their product.

Individual components counted for 40% of each student's final grade, including 25% of the total grade for their individual portfolio. Peer evaluations accounted for 7% of the final grade, and 8% was reserved for instructor assessment of individual contributions.

Student Portfolios

Portfolios provide an in-depth record of the students' work during the semester and, most importantly, their reflections of that work. 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. Despite these advantages, portfolios can also be a tremendous amount of work for both student and instructor. Balancing the benefits of developing a portfolio with recognizing when portfolio components become "busy work" for students can be a challenging task.

Evaluation of portfolios was facilitated by the creation of a rubric, which is a scoring matrix that specifies the caliber of work typified at various levels of performance for each aspect of the portfolio to be evaluated (e.g. depth of reflection, organization and creativity). See Poole et. al., presented in these proceedings, for an example of a rubric [4]. The performance levels included: "*Beginning*," "*Developing*," "*Accomplished*" and "*Exemplary*." By rating the student's work in one of these four categories, instructors reduce grading subjectivity and provide students with concrete feedback to improve their performance. An additional benefit of the rubric is that it serves as an instrument for communicating and clarifying performance expectations between the students and the instructors. Notably, the two instructors demonstrated high reliability in their scoring, which demonstrates its value in reducing subjectivity. The portfolios were evaluated twice during the semester to allow students to implement changes and improve performance.

In one section of the first-year course, students developed their own rubrics, which they then used to evaluate their own performance. For example, one student selected performance levels ranging from "beginner" to "expert," while another chose "bronze" to "gold." Students' learning became more self-directed as they developed the criteria against which they would be graded. Teaching/learning and assessment are combined when students are allowed to participate in determining how they will be evaluated.

Peer Evaluation

Peer evaluation was also a component of an individual student's total grade. Each student divided a hypothetical $1,000 bonus among all team members (including him/herself) accompanied by a rationale for the allotment. Averaging the results among all team members yielded interesting insights for the instructors. Of particular interest was how team members perceived their respective contributions to overall group success and how the workload was actually shared within the team.

Course Assessment

Assessment of a course is vital to determine if the course objectives are being met, and to provide valuable feedback that can be used to improve the course. One form of assessment that is routinely used at CU is the Faculty Course Questionnaire (FCQ), an end-of-semester survey of student perceptions. In both the First-Year Engineering Projects and Invention and Innovation courses, the standard FCQ format was augmented with specific questions that addressed how well the learning goals for the course had been achieved.

In addition to the FCQ, a *class interview* was used to solicit feedback. This tool has been used effectively for many semesters in the first-year course. Although this in-depth process requires two outside people to administer and takes one full class period, instructors consistently learn valuable information beyond that from a written survey (e.g., FCQ).

For the class interviews the students are asked to respond to two questions: "What are the strengths of the course, the instructor, the TA's, and the facility?" and "What are the areas of improvement?" They are first instructed to discuss the questions and reach consensus on their responses in a group of approximately five members. Next, the two facilitators proceed to list the comments on a white-board as the groups take turns in reporting them. After all of the responses are listed, the students individually complete a form marking agreement or disagreement with each statement. For the pilot semester of the Invention and Innovation course, the results of the class interviews were discussed at the end-of-semester debriefing session that was held conjointly for both the first year and upper class projects courses. Several of the following recommendations emerged from this powerful feedback process.

Lessons Learned

Like any pilot activity, much was learned that is being applied to the second offering of this course in fall 1999:

- Portfolio work will be integrated more evenly throughout the course, setting the stage from the beginning of the semester for integrative, reflective writing as a key component of the course. Fewer writing assignments will be required, but those that are will stress the integration of course components, and how they impact the invention and innovation process.
- More short, hands-on creativity and divergent thinking exercises will be dispersed throughout the course.
- Student team formation will couple project preference, diversity of skills, and experience that students bring to the team with an individual's perceived social and communication style.
- Advanced and transfer students must *learn* how to work effectively in teams. Team dynamics and group problem solving exercises promote how quickly individuals begin to function as a team; more course time will be invested in doing them in the future.
- Introducing engineering students to the concepts of entrepreneurship and the experience of inventing requires exposure to a broad range of business topics in addition to disciplined design, building and testing of their product. In the second course offering, more class time will be invested in active-learning discussions that reinforce topics such as evaluation of products currently in the marketplace; intellectual property and patenting; assessing market need for a new product; development of a simple business plan and a pervasive course focus of creative thinking;

Summary

An excellent way to reinforce that "engineering is about building things for the benefit of society" is to help students encounter, first-hand, the complete design-build-test cycle. Experiencing the design process in a setting focused on inventing new products and taking them to the marketplace broadens student's view of the role of engineers in society. Students begin to envision themselves as creators of new products and new enterprises, and learn through doing that they, too, can build things for the benefit of society; that is, they can do *real* engineering.

References

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