Exploring Entrepreneurship through Product Development: A Hands-on Approach

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Abstract

Engineering students of all disciplines typically engage in at least one open-ended design experience during their undergraduate careers. Through hands-on design and build projects, they learn the important steps in product and/or process design. However, engineering students are rarely exposed to the entrepreneurial perspective, in which product success is greatly influenced by market forces in addition to the elegance of the design. An engineer may create a functional and beautiful product, but if it doesn't find a niche in the marketplace, is it *really* a success?

This paper describes an interdisciplinary course for engineering and other students that explores both sides of the product development process. Working in teams, students design, build and test a proof-of-concept product prototype with potential for commercialization. In parallel with their design/build experience, students explore the world of entrepreneurship, including patent searches that guide their designs, learning the difference between an idea and an opportunity, forecasting profitability, understanding the real costs of raising capital, and estimating manufacturing costs.

Teamwork is essential for product development success. Methods to stimulate and develop effective teams will be discussed. Additionally, course assessment techniques and tools will be presented, including pre- and post-course evaluation of both engineering and entrepreneurial knowledge and skills.

To help alleviate the end-of-semester "crunch" characteristic of product development courses, and to promote more professionally crafted product and market documentation, we will describe a method that helps teams write a high-quality, comprehensive Design Report and Feasibility Study by distributing the writing load over the entire semester.

Connecting Open-Ended Design and Entrepreneurship

Open-ended design projects are a key component of most engineering curricula. Historically experienced through a senior capstone course, many engineering schools now include design projects much earlier in the curriculum[2]. The effectiveness of learning by doing is well known[3], leading many programs to follow a design-and-build model. Most engineering design courses apply the design process to solve a specific problem. While manufacturing cost of a design is often considered, that is only one variable in the economic viability equation. The fundamental question of how a product will succeed in the marketplace is seldom addressed in engineering curricula. Business students, on the other hand, explore market viability, but typically have little notion of the technical feasibility of a conceptual product design, considered the realm of the engineer.

Since economic success in the "real world" requires both technical feasibility and economic viability, the premise of this paper is that there is tremendous value and opportunity for a course that integrates both aspects. Now in its fourth year and intended for students at many levels, *Invention and Innovation* is an interdisciplinary course that bridges the worlds of engineering and entrepreneurship[4].

Course Elements

The focus of the *Invention and Innovation* course is to design, build and test a working prototype of a potentially marketable product. Our experience has shown that students are more engaged in products of which they are interested. At a brainstorming session in the first week of class, students generate many potential product ideas, which are then pared to a fewer number through student voting. Each student's product preference is one of numerous factors considered during team formation (described below).

The newly formed teams learn about each other's strengths and weaknesses immediately as they embark on a two-week **creativity project**. Based on a similar project conducted by Faste and Roth at Stanford University[5], student teams design and build a model of an amusement park ride with limited time and materials (foam core, glue, pins, etc.), and incorporating two functioning simple machines. At the conclusion of this intense exercise, instructors have a good notion of team dynamics and potential. Quantitative peer evaluations count 5% of each student's grade, and provide instructors an opportunity to give each student one-on-one feedback that includes instructor and anonymous peer feedback. This immediate feedback is often a turning point for individual team members who have struggled within their team to make a meaningful contribution to team success.

Students are encouraged to "parallel process," that is, to generate potential design solutions for their final products while working on the introductory creativity project. However, project development moves into high gear in the third week. Students brainstorm alternative design concepts, conduct patent searches for competing projects, and identify potential customers for their products. Example projects include:

- **Rota-Ride** — A snowboard binding that allows users to easily adjust foot angle

- **Smart Window** — A casement window that senses indoor and outdoor temperature, along with precipitation, and automatically opens or closes accordingly
- **Tire Deformation Gauge** — A magnetic car tire system that measures tire deformation (and thus, incorrect inflation) and alerts the driver if tires are outside safe parameters
- **Hands-Free Door Opener** — Adaptable to existing entry doors, a proximity sensor detects the approach of the homeowner, and automatically unlocks and opens and closes the door

Course Format

This three credit-hour class meets for five contact hours weekly. In the one-hour lecture period, instructors present interactive lectures on pertinent topics including an overview of the design process, methods to stimulate creativity, the importance of aesthetics in engineering design, etc. Entrepreneurial topics include the difference between ideas and opportunities, intellectual property and the patent process, sources of funding, and break-even analysis. Guest speakers include inventors and entrepreneurs who have led successful product ventures, and a manufacturing engineer who helps students understand manufacturing processes and forecast product costs.

Two studio periods, each two hours long, are usually reserved for group work time. Instructors emphasize that each two-hour studio period represents eight hours worth of work time for a team of four. In addition, successful teams spend considerable time outside of class as well.

Patent Implications

The ability to easily search U.S. patent information on the Internet is invaluable to the entrepreneurial process. During the conceptual design stage, teams search for and examine existing patents that may impact their designs. Students are often discouraged to discover prior art that, at first glance, seems identical to what they thought was their unique idea. The instructors guide them to carefully examine the specific patent *claims*, and help them discover creative and legitimate ways to design around and beyond the existing art.

As part of the feasibility study, teams analyze existing patents and summarize how specific patent claims or design features informed their designs. Figure 1 provides an example of a design analysis for a pin and hole-locking snowboard binding design.

Patent Design Feature	Design Evaluation by Feature
Adapter or integrated into binding?	Integrated
Boot remains in binding?	Yes
Ease of rotation?	Difficult: two spring-loaded pins require two hands and fine finger work
Resolution of rotation?	~20 degrees
Size / weight?	Insignificant
Ability to be rotated while wearing mittens?	Impossible
Snowboard modifications required?	None
Icing / jamming issues?	Ice / grit could get in holes
Durability?	Poor: pins break, holes get jammed, springs get lost and are difficult to replace

Figure 1. Example student patent design analysis of a snowboard binding.

Opportunities for Further Development

Recognizing that it is unrealistic to develop a market-ready product in one semester, interested students are encouraged to continue product development. One funding avenue students pursue is the National Collegiate Inventors and Innovators Alliance (NCIIA), which awards invention team grants up to $20K to fund product refinement and patent application. Four prior student teams have received NCIIA support. Of those, three have filed for patents, one successfully (so far). One of the successful team members was serving as a teaching assistant during the time he heard that his patent had been approved; this was a tremendous motivation for other students to write NCIIA proposals. Another way we encourage interested students to continue product improvement is by supervising independent study courses in subsequent semesters.

Oral and Written Deliverables

Recognizing their important role in the professional arena, oral presentations are required of teams throughout the course:

- In the **preliminary design review,** teams identify the consumer problem their product will solve, specify design requirements and suggest alternative design concepts.
- At the **critical design review**, students provide details on their final design concept, and discuss "design drivers" that have informed their design, including engineering analysis and evaluation of existing patents.
- At the **final presentation**, students demonstrate their functioning (or not) prototypes to the class, evaluate their performance, and present their feasibility study results, including a detailed break-even analysis.
- Working prototypes are showcased in a judged College-wide **Design Expo**, which includes posters describing the products and their economic potential in the marketplace.

Teams also write two comprehensive reports:

- The **feasibility study** examines the economic viability of the product, identifying potential customers, forecasting market size, estimating manufacturing costs, predicting both fixed and variable costs, and computing a break-even sales price and volume.
- A **design report** details how the product evolved through the comprehensive design process, including functional and quantitative design requirements, alternative designs explored, design drivers that impacted the final design, evaluation of prototype performance, and suggested product enhancements.

Just as successful products evolve through iteration, effective documents are improved through evaluation and revision. The significant time pressure inherent in getting prototypes *really* functional to meet the very real and final deadline of the public Design Expo distracts students from focusing on the two comprehensive written reports. To achieve a better end result and distribute the workload more evenly, both reports are prepared incrementally throughout the semester. Teams write short (3-5 page) sections of the feasibility study and design report throughout the semester. The instructors review and return them with suggested revisions, along with encouragement to make the revisions immediately. No grades are given for the draft versions. Once revised, these sections form "chapters" of the final documents, thereby reducing the end-of-the semester demands of final integration and summary evaluations. This approach has significantly improved the quality of the written reports, gives students incentive to continually improve their deliverables, and provides the instructors a coaching opportunity to work with students to improve their written communication skills.

Team Building

Two essential course outcomes are for students to (1) realize the power of teamwork and (2) build a cohesive and productive team. Successful teams have members with diverse technical and social skills, but a shared willingness for hard work and a commitment to team goals. The instructors create teams of four to five members, after considering several factors:
- Individual student product preference, priority ranked
- Technical skills (e.g., CAD skills, hands-on tinkering experience, analytical knowledge, etc.) as determined by a skills assessment survey
- Stated preference to work alone or in teams, spreading the former among the teams
- Instructor observation of student social and communication styles
- Gender — Women students (still underrepresented at traditional engineering colleges) are paired within teams when possible. We have found that the contribution of lower assertive women can be marginalized in predominantly male teams, but that this is minimized when teams have two women members.

Creativity and team dynamics exercises early in the semester "jump start" team member relationships, including:
- A kinesthetic and verbal exercise on the first day of class with the goal of everyone in the class learning each other's first name and a hobby or interest of every other student
- Constructing a sculpture solely from newspaper and masking tape that epitomizes a word or concept that characterizes "creativity"
- Moderately physical team dynamics exercises that provide simple metaphors for effective team communications strategies

- Logic puzzles that facilitate and test group problem solving approaches

Resources to Assist Students to Create What They Dream

Hands-on projects require considerable human and fabrication resources. The Integrated Teaching and Learning Laboratory (ITLL) is a hands-on learning environment that supports intense design and build activity[6]. Interactive design studios feature team work areas, workbenches with hand and small power tools, and a computer for each team to conduct Internet searches and build computer-aided design models, etc. The Manufacturing Center contains several CNC machine tools (milling machines, lathe), CNC laser cutters for high precision fabrication, a rapid prototyping system, as well as conventional woodworking and machine tools. The Electronics Center provides the capability for students to simulate, fabricate and test basic electronic circuits.

In addition to tools, technical support is available. Both the Manufacturing and Electronics Centers are professionally staffed during daytime working hours throughout the semester, and evening hours in the last eight weeks of the term. Two undergraduate teaching assistants, "veterans" of former design/build courses, provide guidance during class studio times, and a "roving" graduate CAD/CAM teaching assistant is available for one-on-one consultation. Other ITLL staff members provide expertise in sensors, LabVIEW programming, etc.

The availability of these resources empowers students to attempt challenging projects with no previous expertise, usually with excellent results. Students create comprehensive CAD models, machine complex parts, and build sophisticated electronic circuits using this "just in time" model.

Assessment and Continuous Improvement

Team Component — Modeling the professional world in which product development occurs in a team-based setting, 70% of each student's course grade is based on team performance. Factors include the initial creativity/mini-design project, oral design reviews, overall product quality (including how well design requirements were met), thoroughness of the feasibility study, and the effectiveness of the Design Expo poster.

Individual Component — The remaining 30% of each student's grade is 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 divides a hypothetical $1,000 bonus among all team members (including him/herself) accompanied by a rationale for the distribution. Averaged results usually give 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 contribute their own evaluation of each individual's performance.

Faculty Course Questionnaire — An 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 is augmented with questions that address how well the course learning goals were achieved. Students rate this course overall as a "B+," with the biggest negative factor being workload, which students rate at 7.9 on a 10-point scale (5 = "OK"). Students clearly enjoy the design and build aspects of the course, but find the workload overly strenuous relative to their other courses.

Student Group Interview Feedback Session — In addition to the standard FCQ, a third party conducts a class interview to solicit in-depth course feedback[7]. Suggestions for improvement from each semester are carefully evaluated when planning the next course offering. The majority of the students agree that the course's strengths are:

- Combining engineering and business principles
- Experiencing the hands-on design process
- Being able to choose the product they invent
- Having a product, not only a grade, to show for the class
- Working in teams
- Presentation experience
- Showcasing their product at the public Design Expo
- Quality of the resources available in the ITL Laboratory for product design and fabrication
- Technical support provided in the ITL Laboratory
- Engaging outside entrepreneurs who share their start-up experiences during guest lectures

Suggestions for improvements include:
- *Require* the use of brainstorming even more (noting that they understand its value, but just won't do it on their own)
- The addition of a marketing student to each product team
- Increasing course credit or reducing the workload
- Closely monitor project complexity to ensure teams do not "bite off more than they can chew"

Innovation Skills Assessment Surveys — Since a major course intent is to improve students' innovation skills, a 31-point self-assessment skills survey is administered at the beginning and end of the semester[8]. The questions are aggregated into eight basic dimensions reflecting course learning objectives:
- Introduction to engineering methodology
- Open-ended hands-on design experiences
- Development of productive study practices
- Development of communication skills
- Interdisciplinary teamwork skills
- Introduction to intellectual property and the patent process
- Introduction to entrepreneurship concepts
- Integrative and creative thinking skills

Analysis of pre- and post-course data showed statistically significant improvements in all of the above dimensions, as seen in Figure 2.

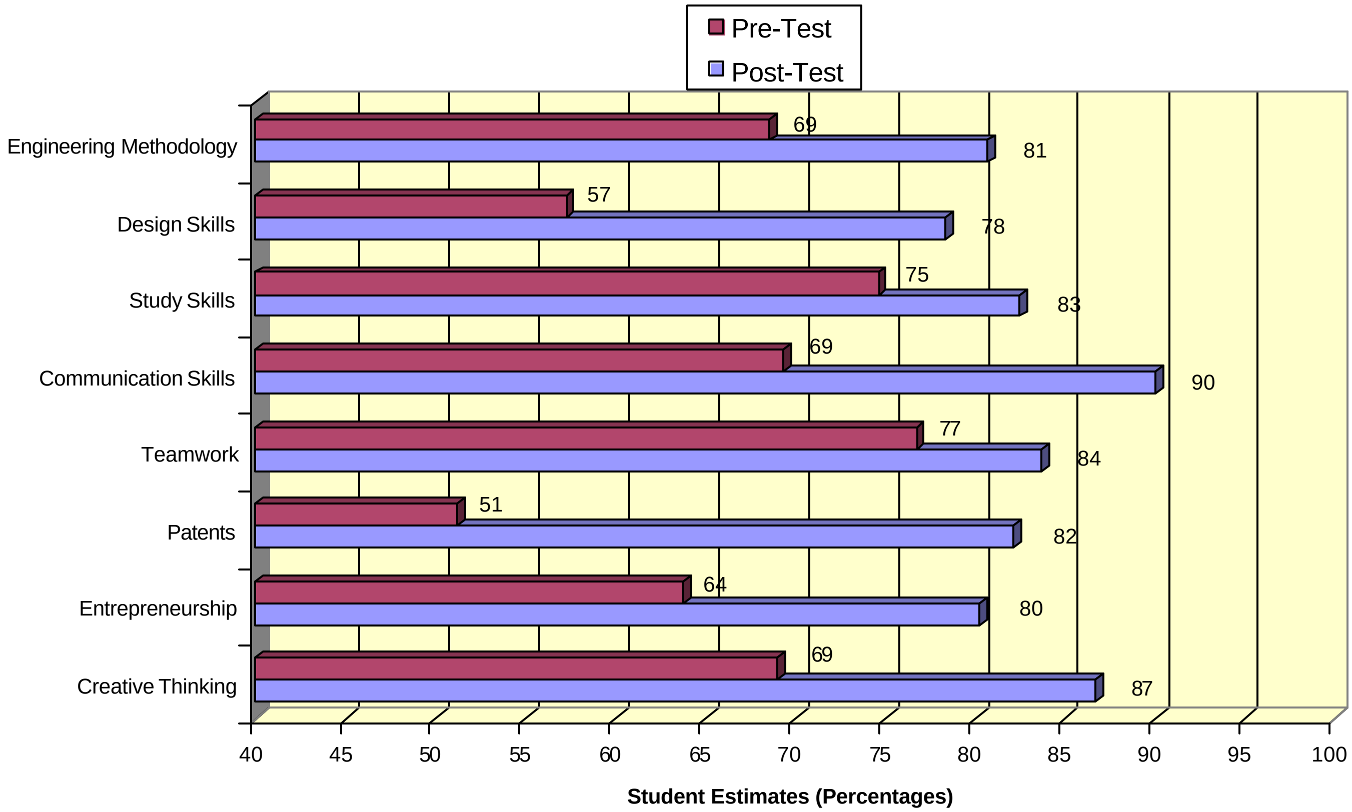

Figure 2. Pre- and post-course assessment results

Collaboration with Business and Future Plans

Early in the development of the course, a faculty member from CU's Leeds College of Business developed a guest lecture series focusing on entrepreneurship aspects of product development. Topics included characteristics of entrepreneurs, converting ideas into opportunities, sources of funding for innovation, etc. The lectures were timely and informative, and the material is considered to be essential to a successful invention and innovation course. However, because the course is already team-taught by both authors, students found the addition of a third instructor to be confusing. In subsequent course offerings, one of the authors has led the entrepreneurship discussions, and has guided teams through a detailed break-even analysis for their products. This approach has been far more effective, as the entrepreneurship discussions now target the specific products under development by the students that semester, and the entrepreneurship topics are pervasive throughout all elements of the course. Students evaluate these course components as valuable rather than seemingly "add on."

In the past, an occasional student from business has taken the course, but the students continue to be predominately from engineering. Given the importance of input from both fields, we intend to make this course more attractive to business students by cross-listing it in both engineering and business. In addition, we are also renumbering the course at the junior level (it is presently a sophomore level course) to facilitate cross listing. Renumbering will also make the course a viable technical elective option for engineering students.

Conclusion

We continually reinforce to our students that "engineering is about creating things that benefit society." A corollary is that a product cannot impact society if it doesn't succeed in the marketplace. Just as a good project-based design course emphasizes *process* more than *product*, this *Invention and Innovation* course teaches students first-hand the process of entrepreneurship, leaving them seeds that can bear fruit later in their careers, if not on the specific product they invented in this course.

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