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Bridging the Gap between Invention and Innovation*

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Bridging the gap between widgets that work but would never sell, and abstract entrepreneurial enterprises with little grounding in physical reality, students in an Invention and Innovation course create and test products with a focus on their potential to succeed in the marketplace. The primary component of the course consists of parallel activities: designing and building a proof-of-concept product prototype (invention), while exploring its potential for commercial success (innovation). Based on the precept that a foundation for entrepreneurship is to inspire engineers to perceive themselves as inventors, and arm them with the capabilities and confidence to tackle the marketplace, this paper describes an approach to convince students, through doing, that they do *have what it takes to become an inventor and entrepreneur.*

INTRODUCTION

ENTREPRENEURSHIP fuels the global economy by creating innovative products that meet market needs and generate profits for their producers. While engineering students traditionally experience design/build projects in their college curricula, the focus is typically on creating a functional *product*, as opposed to one that has a strong potential to succeed in the marketplace [1]. Business students, on the other hand, tend to study the *process* of entrepreneurship, but gain little experience in creating functional products. The 'Invention and Innovation' course described here bridges this gap by having student teams design, build and test functional product prototypes while examining the factors that will determine success (or failure) in the competitive marketplace.

Invention and Innovation is a 15-week junior-level general engineering technical elective that is team-taught by the authors and open to students of all majors on campus. The course capitalizes on the technology-rich electronic and mechanical fabrication capabilities of the Integrated Teaching and Learning Laboratory [2]. Details of the course elements and structure have been described elsewhere [3]; this paper explores some of those elements in more depth through several example products, and provides a discussion on what has been learned to continually shape the course.

GETTING STARTED

Product brainstorming

Day one finds randomly chosen teams of 4–5 students creating newspaper sculptures to epitomize the concept of creativity, with students targeting specific design goals and working within material and time constraints. Through other ice-breaker exercises, the 30 students and two instructors know each other by first name by the end of the first two-hour studio. For the first homework assignment, each student generates a written list of 25 ideas for potential new products, typically focused on 'things that bug you' in everyday life. A subsequent large-group brainstorming exercise generates new product ideas. Using stick-on dots, each student casts three votes for what they consider the most promising and interesting ideas, winnowing the list of 65 or more products to about eight. The instructors may exercise power of veto for any of several reasons:

- The technical scope of the product is too complex (e.g. instant automobile air-conditioning).
- The technical scope of the product is too simple.
- The product is offensive to either instructor.
- The product is deemed by instructors to be harmful to society (e.g. single cigarette dispenser).
- The product promotes illegal activity (e.g. police radar jamming device).
- The product flunks the 'front page' test (i.e, how would it affect the reputation of the university if featured in the local newspaper?).

Team formation

One course goal is for students to experience and appreciate the power and effectiveness of diverse teams; therefore, the semester-long student teams are thoughtfully formed, based on several factors:

- Individual student social styles (self-assessment and instructor observation following a social styles workshop).
- Student product preference (trying to accommodate each student's first, second or third choice).

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- balance of technical skills (CAD, hands-on 'tinkering' experience, electronic skills, etc.);
- preference for working alone or in teams (avoiding teams comprised predominantly of 'lone-wolf geniuses').

Out of class, the instructors spend several hours balancing these factors to form teams of four or five students, a group size large enough for students to be productive and experience the challenges of coordinating and managing a large, diverse team.

Ice-breaker project

Teams are immediately immersed in a short, intense 'warm-up' project that requires rapid product prototyping using constrained materials, and forces students to get out of their comfort zones. To be successful, teams must coordinate out-of-class work time during the weekend. Projects are graded according to strict performance criteria and factor into each team's final grade. Peer evaluations also impact individual students' final grades, and provide instructors with an early indicator of any team dynamics issues.

Inspired by others

The ABC Nightline video, featuring the product design firm IDEO redesigning a shopping cart in five days, is shown to introduce students to the concept of 'fail often to succeed sooner' [4]. The video is inspiring and motivational, and reinforces the importance of rapid prototyping and the value of diverse, creative multidisciplinary teams.

PRODUCT INVENTION SIDE-BY-SIDE WITH INNOVATION

The primary component of the course consists of parallel activities: designing and building a proof-of-concept product prototype (invention), while exploring its potential for commercial success (innovation). The product prototyping follows the traditional engineering design process [5]. Entrepreneurial topics, such as evaluating the customer and market, and forecasting profitability, are explored through weekly class discussions and reinforced by iteratively creating a feasibility study. In-class break-even analysis workshops with individual teams focus on each unique product and market situation, and force students to become realistic about start-up and production costs.

Exploring and protecting intellectual property

While conducting on-line patent searches, students explore the intellectual property ramifications of their product. Students are frequently disheartened when they discover that 'their' product has already been invented! However, the budding inventors are encouraged to dig deeper and analyze what the existing patents cover, and how prior art can both inform their design and be designed around. The teams submit a paper summarizing this phase of the product design, which includes a matrix and explanation showing how the results of their patent research helped to evolve their unfolding product design.

For example, one team conceived of a 'smart' window that would automatically open or close depending on weather conditions. They were discouraged when they discovered a patented system that would do just that. However, the patent protected the application of this concept to a double hung window, leaving casement windows fair game to the student inventors.

Struttin' their stuff

Functioning products are showcased at the end of each semester at a judged college-wide Design Expo, which constitutes public disclosure of their invention and starts the 12-month 'clock' protecting intellectual property rights under U.S. patent law.

New venture funding sources

Discussions on raising financial capital to help develop and market products make students more aware of the broad range of investment options. They are usually astounded at investors' expected rate of return in exchange for up-front funding, as well as the amount of control over operations certain types of investors may demand. Some teams subsequently write grants to obtain NCIIA funding[1] to support continued product development.

Break-even analysis

The bottom line (which offends some students) is: 'Can you make money with this product?' To address this crucial question, students explore the fixed, direct and variable costs for creating and marketing their invention, forecasting anticipated revenue determined by sales price and volume. Engineering students, who tend to focus on manufacturing costs, often overlook the magnitude and diversity of fixed costs, such as insurance, rent and personnel. Since realistically estimating manufacturing costs is unfamiliar territory to most engineering students, an expert in cost estimating works with individual teams to help the students generate realistic bills of material and production cost estimates.

Starting with a spreadsheet template, teams work individually with the instructor to develop a model for predicting the break-even point for their product, determining under what set of conditions their enterprise would become profitable. This requires students to consider many factors, including market demographics, estimated

[1] National Collegiate Inventors and Innovators Alliance, http://www.nciia.org/.

potential demand, competition and product pricing. Students often make the assumption that setting low prices will maximize profits through high sales volumes. Use of the break-even model, coupled with in-class discussions focused on product pricing, shows students that 'low ball' pricing is usually not an effective strategy. The model allows students to perform valuable trade-off analyses, and highlights areas in which they need to focus cost-reduction efforts. This valuable exercise helps students hone in on a product price that is realistic with respect to future profits.

Guest entrepreneurs

The participation of guest entrepreneurs provides external validation for the course. Guest speakers must be especially engaging, bringing to the class a variety of successful (or not!) products with which they have been intimately involved. One particularly effective speaker is an electrical engineer who made it big in the early 1990s, went bust with what should have been the 'perfect' high-tech startup, and now successfully produces and markets high-end (and high-priced) knee pads. It is enlightening for engineering students to hear that his success is 10% due to technical expertise and 90% to business 'savvy.'

DELIVERABLES

To reinforce the concept that success in entrepreneurship is linked to one's ability to sell ideas, students make oral presentations and produce several written documents, in addition to designing and building a proof-of-concept, working prototype of their invention.

Ice-breaker project demonstration

In this informal class presentation, students describe the marvelous features of their initial team project, and then demonstrate it with enthusiasm in a short 'commercial'.

Preliminary design review (PDR)

In this oral presentation a third of the way into the course, student teams present the design requirements for their product and several alternative design concepts that could meet those requirements, benchmark competing products, offer an analysis of their target customers, and describe the anticipated customer benefits. They also present a project plan for product development and provide candid reflections on their team's performance.

Comprehensive design report

In this written report, which is due 60% through the course, teams document their final design direction. Their quantitative decision analysis shows how they selected their final design from the alternatives presented at the PDR, describes their design in detail (including CAD models) and identifies design drivers that influenced their design, such as appropriate engineering calculations, market surveys, patent analysis, etc. They also update their project plan and provide further reflection on their team's performance.

Feasibility study

Each student team prepares a written feasibility study that summarizes the entrepreneurial aspects of their invention. To distribute the course workload, section drafts are due throughout the semester; each section is returned with editorial suggestions for revision, so the final feasibility study requires minimal new writing. The feasibility study contains an in-depth patent analysis of prior art, including how it influenced the design, a customer analysis (numbers, demographics), materials selection analysis and final bill of materials, and a break-even analysis.

Product brochure

Students prepare a color, tri-fold flyer containing information of interest to potential customers, such as product features, benefits and specifications, as well as labeled graphics that describe the product.

Design Expo

At the end-of-semester Design Expo, students showcase their product inventions alongside approximately 60 other engineering student design projects. In addition to showing their wares and being judged, each team prepares a color poster describing their invention and why they think it will be a commercial success (or not!).

Final presentation

An oral presentation in lieu of a final exam provides opportunity for students to summarize how effectively their inventions met their objectives and forecast the future potential for their product.

SELECTED EXAMPLE INVENTIONS AND TEAMS

Student inventions tend to be unique and the instructors are continually amazed at the creativity and drive of multidisciplinary invention teams. Two illustrative product and team examples are described below.

RoadSki

This team set an ambitious design requirement: their RoadSki invention would simulate downhill alpine skiing on pavement at speeds of up to 45 mph. The instructors believed this was unrealistic; however, at their final presentation, students took great delight in showing a video of their product doing just that (Fig. 1). Even though two team members engaged in power struggles during the early stages of the project, all members worked

Fig. 1. The RoadSki invention simulates downhill alpine skiing on pavement—at speeds of up to 45 mph!

hard and exemplified IDEO's 'fail often to succeed sooner' philosophy. They moved quickly into the physical realm, and created and tested numerous rough but functional prototypes, which, through peer pressure, stimulated other teams in the course to follow suit.

The RoadSki team submitted a proposal for NCIIA E-team funding, but was turned down for valid safety concerns. One of the team members subsequently became a main contributor to two NCIIA-funded E-teams. Through these experiences, he became so enthusiastic about the field of innovation that he exploited a little-used option that allows students to design their own major. He combined courses in mechanical engineering, business and biomechanics to earn a multidisciplinary B.A. degree focused on invention. One of the co-authors served as his senior thesis adviser on yet another invention that combines energy-efficient light-emitting diodes (LEDs) and powerful rare-earth magnets to create a bicycle taillight that does not require batteries. The simple electrical generator has no discernible drag, so the light can always be on. The budding entrepreneur is currently exploring patent possibilities, and negotiating with manufacturers interested in producing and marketing this unique light.

Portable wireless access

With today's technology, wireless communication is difficult in remote regions. A creative team of engineering students successfully prototyped a portable, solar-powered, wireless access system that could withstand harsh environmental conditions (Fig. 2). The team of five students enough to weather one 'slacker,' as well as overcome gender bias issues associated with a highly competent, outspoken woman on the team. Even though the sole female team member had an amazing academic track record, including a B.Sc. degree in biochemistry and an M.A. in art history, she was initially perceived as too 'artsy' by her colleagues for significant technical contributions to the project. This strong and talented woman persevered to prove her teammates wrong; she received the top grade in the class and in the end was highly valued by all on her team.

Another team member developed a second functional wireless access system prototype through an independent study the following semester. Dubbed the LightWave, this product was launched in February 2004, backed by over $50K from private investors. A related product, based on earlier prototypes, was field tested in Iraq in 2003, generating sales interest from the U.S. military.

Fig. 2. Portable, solar-powered wireless communication access point.

ASSESSMENT

Following the philosophy 'Don't tell me what's right—tell me what's wrong,' this course is heavily assessed every semester to enable continuous improvement. In that spirit, the co-instructors appreciate the positive feedback and make sure to retain highly rated course elements, but they focus on suggested improvements, implementing all feasible suggestions.

Prior to the initial course offering, the co-instructors developed a detailed assessment plan and matrix that identified nine specific course goals. For each goal, they determined learning objectives (what each student should be able to do and know at course completion), and established the performance level required to meet each learning objective. The evaluation methods we employed were designed to collect data and assess student performance against each performance criteria. As a result, we developed a variety of assessment tools that continue to evolve with the course. Assessment tools include a facilitated student group interview session, periodic instructor/team meetings, written peer evaluations, pre- and post-course skill evaluation surveys, and the university-required faculty course questionnaire (FCQ)

FCQs

Summarizing results of the FCQs administered at semester-end over seven course offerings found that students consistently rate the course as a good learning experience, with an overall course rating of 'B+.' Early FCQ results also showed that students considered the workload very high (as high as 7.9/10, where 5 = OK). This FCQ rating encouraged careful examination of course requirements and elimination of those that did not focus, like a laser, on the major course goals of *invention* and *innovation.* As a result, more recent FCQ results show more reasonable workload ratings.

Student goup interview feedback sessions

The FCQ assessment does not provide adequate detail for incrementally improving the course, and, thus, is augmented with an end-of-semester student group interview feedback session and pre- and post-skill evaluation surveys. At the conclusion of each semester, an outside facilitator solicits feedback for course improvement through an in-class student group interview evaluation process. All aspects of the course (professors, projects, assignments, in-class discussions, specialty workshops, guest speakers, facilities and equipment) are discussed. With the instructors and TA absent, newly formed groups averaging five students each spend 10 minutes discussing and creating a list of *course strengths*, recording only those in which the group reaches consensus. Each issue must be worded so that other students can later agree or disagree with the statement. During the next 10 minutes, the groups prepare a list of *suggestions for course improvements*, wording the suggestions specifically such that instructors could act upon them for the next course offering (e.g. 'add more 'how-to' instruction' vs. 'the manufacturing workshop is not effective'). After each small group has completed both lists, the items are compiled into one master list on the classroom board. Each student individually and anonymously votes on a computer-tabulated form the degree to which s/he agrees or disagrees with each statement on a scale of 1 to 5. A recorder also takes notes during this session, anonymously capturing exact student quotations.

Suggestions for course improvement were most often related to specific assignments or facilities issues, and usually led to course improvements in successive years. Students clearly enjoy the course, but struggled with the heavy workload in the first two offerings. Early alterations to the course—the addition of more creativity and team dynamics exercises, and significantly greater emphasis on the entrepreneurship components—in fact, increased the workload to an unacceptable level, as verified by FCQ data. In the third year, the workload became more manageable by eliminating portfolios, reducing the number of team presentations, and requiring fewer reflective writing assignments. Minor course revisions are continually made to make more time available for students to focus on their product invention and innovation, and conduct more thorough profitability analyses.

Recent improvements based on student feedback include setting a deadline for functioning prototypes two weeks prior to the Design Expo, reducing the number of oral presentations, and shortening the introductory ice-breaker project to allow students to begin working on their inventions sooner. And, we are launching an ITL Laboratory student user group to explore other suggestions, including longer access hours that would affect all student users of the facility.

Peer evaluation

Two peer evaluations, each comprising 5% of the course grade, encourage students to take their contribution to team success seriously. The first evaluation is conducted at the end of the 'warm-up' creativity project, and the second at the end of the course. Each student divides a hypothetical $1,000 bonus among all team members (including him/herself) accompanied by a rationale for the distribution. Student results are thoughtful, and usually confirm instructor observations. Averaged results across each team provide a clear picture of each team's high and low achiever. Typically, low achievers rate their own contributions low, although they usually do not rank themselves as low as do their peers. We meet privately with each student after the first peer evaluation, helping the student to better understand their peers' perceptions of their contribution and develop strategies for improving their contribution (if warranted). This meeting can be a significant turning-point in the course if students realize they are not pulling their weight on the team.

Innovation skills assessment surveys

We conduct a skills survey at the beginning and end of each course to measure student self-estimates of eight skills that comprise the course's learning objectives. As seen in Fig. 3, students reported improvements in all skill areas, consistent with results reported previously [3]; seven of the eight increases are statistically significant ($p < 0.05$). We believe that the reason the skill area, knowledge of engineering methodology, did not increase significantly is that the upper division engineering students considered their skill in this dimension high when they started the course.

CONCLUSIONS

Students report that this course is a lot of work (sometimes too much)—but that it is very

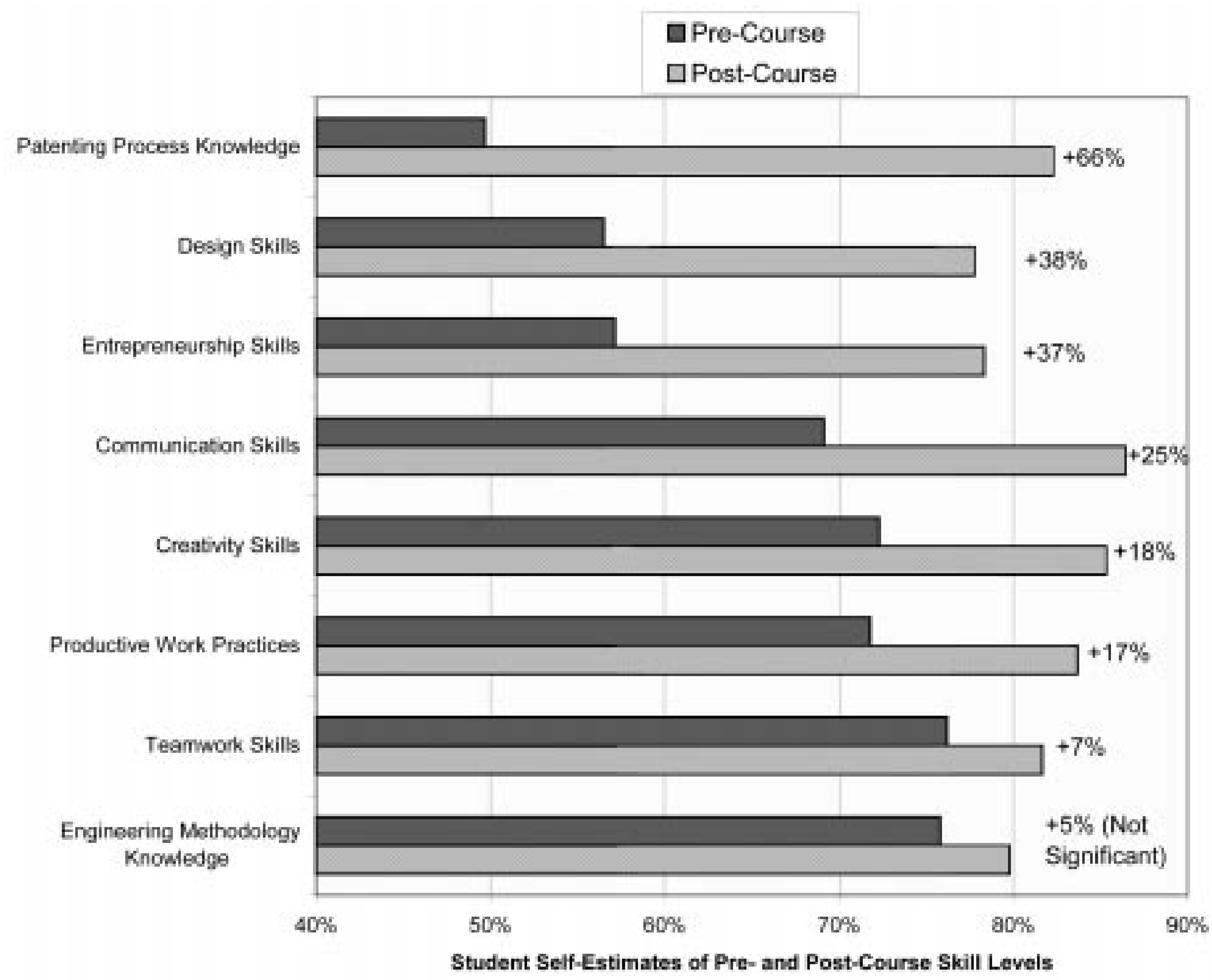

Fig. 3. Skills survey results averaged across three course offerings (fall 2001, spring 2002, fall 2002). All results are statistically significant ($p < 0.05$) unless otherwise noted.

rewarding. For the instructors, the course is extremely satisfying; they get to know students well, and see them emerge from the course empowered to tackle the challenges of innovation for the marketplace. While many students are content to finish the course and move on, others are eager to take their invention further and pursue this avenue through independent study. We are considering a follow-on course in which students could refine their prototypes, perform more in-depth engineering and marketing analysis, write an NCIIA grant proposal and file a provisional patent application. Although not universally true, a course such as this appears to be an effective 'jump start' into entrepreneurship for a growing number of students.

Like the design process itself, this course improves through iteration. Some of the lessons we have learned include:

- Create an expectation and provide support so that highly functional teams are developed.
- Focus on building community by reinforcing name use, and cultivating a shared awareness and value for varied communication and social styles.
- Relentlessly focus on *process* as much as *product*.
- Eliminate course deliverables that do not *directly* support either product or process.
- Allow students time to concentrate on product completion during the intense period at semester end.

Additional information on the course may be found at: http://itl.colorado.edu/GEEN3400.

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