AC 2007-728: ENTREPRENEURIAL ENGINEERING CAPSTONE COURSE WITH RESEARCH-BASED OUTCOMES ASSESSMENT

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Abstract

Capstone engineering design courses play pivotal roles in development of engineering students' professional skills needed for innovation in a globally-competitive technological world. This paper describes a two-semester course sequence, jointly taught by faculty in engineering and entrepreneurial studies, that integrates engineering design and business development. Course outcomes are defined based on research that established four performance areas addressing student and solution development in capstone design courses: personal capacity, team processes, solution requirements, and solution assets. Performance criteria for each area establish definitions of desired student achievement in each area and form the basis for assessment of outcomes for the capstone engineering design course.

Course outcomes are assessed using two or more exercises for each of the four areas of performance. Each exercise is accompanied by a scoring rubric based on factors associated with that performance. Each is also aligned with ABET outcomes to provide useful performance data for program assessment. Assessment exercises are recommended for formative and/or summative use in capstone design courses. Assessment exercises for personal capacity, team processes, and solution requirements are being pilot tested, while those for solution assets are under development. This assessment system offers rubric-based direct measures for student performance, which is important for course or program assessment and improvement.

Results of the jointly-taught entrepreneurial engineering capstone course have been encouraging. Students have demonstrated impressive growth in professional skills and have produced solutions that have significant business potential. Project sponsors, industry advisors, and business plan judges note admirable achievements of student teams. This course model is offered to stimulate transformation of capstone design courses to outcomes-driven student learning experiences that can better prepare graduates for global challenges of the future.

Introduction

National leaders are sounding the alarm: The United States is losing its competitive edge in the global marketplace[1]. Some perceive that the nation is not preparing adequate numbers of people in technological fields, such as the engineering disciplines. Additionally, they contend that many graduates are not sufficiently prepared to address technological challenges they will face under global competition. Many business leaders declare that innovation is absolutely critical for our nation to survive economically and militarily. If our nation is to prosper, our educational system must be transformed to produce technology and business innovators[2].

A common context for preparing engineering students for professional practice is the capstone engineering design course, found in nearly all baccalaureate engineering degree programs in the US. These courses typically engage senior-level undergraduates in team-based project experiences simulating selected aspects of professional practice. In this project context, students' design, problem solving, and professional skills are developed and tested. Students' projects frequently are client-sponsored, instructor-initiated, student initiated, or social oriented. Their design products typically are evaluated against expectations of potential users and instructors. Students have excellent professional development opportunities as they interact with project stakeholders around project developments.

Typical capstone engineering design experiences stimulate student development of both technological products and professional skills. Both students and faculty recognize that learning associated with these courses is different than occurs in many other engineering classes, but many disagree on appropriate learning outcomes for the course. Critical questions are:

(1) What should and have students learned and demonstrated through their capstone design courses?
(2) Do these abilities match the public's expectations for graduates who will be leading technical and business innovation for our nation in coming years?

As demonstrated by these questions, capstone design course instructors must give proper attention to defining, accomplishing, and measuring achievements of targeted student learning outcomes. ABET accreditation requirements reinforce the importance of these measures[3].

Goal

The goal of this paper is to present an entrepreneurial engineering design course that rigorously addresses student learning outcomes derived from a research-based definition of learner and solution development in capstone engineering design courses. This course is offered as a model for capstone engineering design courses that develop future technical business innovators. In the following sections, we describe the course and its context, present four areas of performance from which learning outcomes emerge, and describe ways in which assessments are imbedded to document outcomes achievement. We conclude by describing notable achievements in student learning and solution development.

General Course Description

For the past two years, an entrepreneurial engineering design course sequence has been piloted at Washington State University. The course sequence is taught jointly by Dr. Denny Davis, professor of Bioengineering, and Dr. Jerman Rose, professor of Entrepreneurial Studies, to provide an integrated entrepreneurial product development experience. Over the past two years student participation has increasingly required formal course enrollment.

Students enrolled in the entrepreneurial engineering capstone course are comprised of three cohorts that add useful diversity to the mix. Approximately one-third are bioengineering seniors enrolled in their senior design course. Another third is a mix of engineering, business, and science seniors participating in a special corporate-sponsored scholarship program, for which a multidisciplinary project experience is a requirement. The final third is a group of engineering and business seniors who, during the previous summer, participated in an internship program introducing them to entrepreneurship. The second cohort is assigned to projects associated with the sponsoring company. The first and third cohorts are intermixed to match student interests and expertise to projects identified by instructors, friends of the university, or students themselves.

The capstone course sequence engages students in multidisciplinary teams working on different projects, all spanning two semesters. In the 2005-2006 academic year, thirty four students participated in eight project teams, as described in Table 1. Similar numbers of students and teams are involved in 2006-2007. Projects were selected based on student interest and the apparent potential of the project to both provide an engineering challenge and to offer business potential. Students were assigned to teams by matching student preferences and backgrounds to project needs.

Table 1: Projects Used in 2005-2006 Capstone Design Course Sequence

Project	Team Composition
Large scale decal application process for aircraft	Marketing, Civil engineering, Chemical engineering, Physics, Accounting
Laser alignment system for manufacturing	Management information systems, Mechanical engineering, Computer science, Finance, Physics, Mathematics
Treadle pump for irrigation in Malawi	Entrepreneurial studies, Mechanical engineering, Bioengineering, Bioengineering
Energy recapture from domestic anaerobic digestion of waste	Entrepreneurial studies, Bioengineering, Biological systems engineering
Manual wheelchair that elevates users	Bioengineering, Mechanical engineering, Business law, Bioengineering
Biofeedback for stress management	Entrepreneurial studies, Electrical engineering, Bioengineering, Bioengineering
Horse saddle cinch tensioning device	Entrepreneurial studies, Bioengineering, Bioengineering, Mechanical engineering
Bioelectrical signal teaching kit for K-12 science	Bioengineering, Management information systems, Bioengineering, Bioengineering

The two courses are taught following a philosophy that students need to be self-motivated for both learning and solution development. Class time is used to provide students common group experiences and to build essential foundations in terminology and tools needed in the projects. Students are required to achieve and document significant progress in:

(a) product development,
(b) business development, and
(c) personal (team and individual) development.

A typical schedule for the two course sequence is summarized in Table 2. As shown, class topics alternate among team development, solution development, and business development issues. Typically the first term produces a solution concept and tentative business plan, and students make presentations at a business plan competition and in class. The second term produces a design solution and business plan with testing or market data, and students again present at a business competition and at a class final project defense.

Table 2: Course Topics for Two-Semester Capstone Course

Wk	***Semester 1 Topics***	***Semester 2 Topics***
1	• Course goals and outcomes; feasibility analysis • Product/business development processes	• Course goals and outcomes; review of business plan feedback • Review project specifications and timeline
2	• Preliminary project feasibility reporting • Team assignments to projects	• Prototype plan: specifications, justification, functionality, budget
3	• Team performance; presentation skills • Project milestones; project management	• Team operational plan • Market research plan • Prototype testing plan
4	• Project stakeholders; needs and requirements • Intro to business plans; stakeholder interviews	• Elevator presentations
5	• Team project feasibility presentations	• Prototype progress reviews
6	• Professional growth; self-assessment • Methods for generating creative ideas	• Prototype progress reviews
7	• Business opportunities; business types • Selecting & improving ideas (Pugh method)	• Finances for business models
8	• Concept architecture & prototyping • Initial prototype preparation	• Team progress reviews (part 1)
9	• Preliminary prototype presentations • Preliminary business plan preparation	• Team progress reviews (part 2)
10	• Intellectual property • Prototype budgeting/finance	• Business plan rehearsal (part 1)
11	• Conceptual prototype review • Business models	• Business plan rehearsal (part 2)
12	• Conceptual business model review	• Feedback on business plans
13	• Business plan preparation	• Business plan competition
14	• Business plan presentation to class • Business plan competition	• Formal design and business reviews
15	• Reflection on course and learning • Course and team reviews	• Reflection on course and learning • Course and team reviews

Course Goals and Learning Outcomes
The overall goal of the course is to prepare students for the professional challenges they will face in entrepreneurial technical product development in a competitive business environment. This is the reason that projects are selected for their business potential and engineering substance. Moreover, project teams are continually pressed to think as entrepreneurs, not as students, in order to elevate their creativity and motivation for producing innovative business ventures.

Course outcomes encompass both learner development and solution development. More specifically, four areas of performance are identified for capstone engineering design courses based on research conducted under a grant from the National Science Foundation, entitled "Transferable Assessments for Capstone Engineering Design."

Learner development outcomes are defined under two areas of performance:

(1) **Personal Capacity (PC)**: Individuals performing and improving individual skills essential to engineering design
(2) **Team Processes (TP)**: Teams developing and implementing collective processes that support team productivity in design

Solution development outcomes are defined under two additional areas of performance:

(3) **Solution Requirements SR)**: Definition of targeted design solution performance and features expected to satisfy stakeholder needs and constraints
(4) **Solution Assets (SA)**: Results from a design project that meet needs and deliver satisfaction and value to key project stakeholders

Personal capacity achievements are seen in individual students' abilities to apply knowledge and to grow their knowledge and skills. Typical examples include abilities to: explain the product development process, explain how pricing affects product success, explain project merits to a lay audience, or learn and use new software for solution analysis. Personal capacity performance is measured against this performance criterion:

> *"Individuals accomplish challenging goals related to design by employing goal-driven initiative, competence in problem solving, integrity and professionalism, and ongoing reflective development of their personal abilities."*

Team process achievements include those procedures used to achieve desirable team dynamics or team productivity. Performances are seen in demonstrated understanding of the processes used and how to improve these processes. Typical team process performances may include: making member work assignments, allocation of resources, conflict resolution, reviewing team and member performances, team communication protocols, and team decision making. Team processes performance is measured against this performance criterion:

> *"The team achieves challenging goals in productivity and team function by strategic use of team resources, synergistic collaboration, decisions that add real value, and assessment-driven refinement of processes."*

Solution requirements achievements are evidenced by students' understandings of needs and constraints that must be satisfied for a solution to have greatest value. Some requirements are derived from user needs, some from needs of manufacturing and maintenance personnel, some from finance and marketing people, and others from society and the professions. Typical specifications of solution requirements include: solution functionality, solution cost limitations, installation time constraints, safety requirements, environmental regulations, and product appearance. Solution requirements performance is measured against this performance criterion:

> *"Stated requirements reflect an in-depth understanding of customer needs, business issues, state of the technology, and societal concerns about the solution, while providing clear targets for the development of a valuable solution."*

Solution assets achievements are valued products and benefits associated with the project solution. These assets are judged using specifications defined in the solution requirements. They may be tangible benefits from product functionality, or intangible benefits that possess value in the eyes of recipients. Typical solution assets are: prototype devices, design drawings, business models, marketing strategies, pride of ownership, or feelings of security. Solution assets performance is measured against this performance criterion:

> *"Design solutions meet or exceed expectations of stakeholders by delivering proven value in desired functionality, economic benefits, implementation feasibility, and favorable impacts on society."*

Assessment of Outcomes

Student achievement is assessed through exercises aligned with the four areas of performance. These are imbedded in the courses to support student learning while being minimally intrusive. Most assessment exercises can both support formative feedback to improve learning and make summative judgments of achievement for grading. To date, assessments for three of the areas of performance are developed and being pilot tested as part of the NSF research project. Assessments for the solution assets area are in early stages of development. Table 3 identifies assessment exercises for the four areas of performance (PC, TP, SR, and SA), along with suitable timing and purposes for using each. Relevant ABET outcomes for which performances can be measured are also noted for each assessment exercise.

Table 3: Summary of Assessment Exercises by Outcome and Recommended Usage

Exercise (Area)	**ABET Outcomes**	**Recommended Usage**
Personal Growth (PC)	○ 3g Communication (written) ○ 3i Lifelong learning	○ Formative: midway in project ○ Summative: end of project
Professional Practices (PC)	○ 3f Professional & ethical ○ 3g Communication (written)	○ Formative: midway in project ○ Summative: end of project
Team Member Citizenship (TP)	○ 3d Teamwork	○ Formative: (2x) early in project ○ Summative: end of project
Team Process Development (TP)	○ 3d Teamwork	○ Formative: early in project ○ Summative: midway in project
Stakeholder Needs (SR)	○ 3h Solution impact	○ Formative: early in project
Project Outcomes (SR)	○ 3h Solution impact	○ Formative: early in project
Solution Specifications (SR)	○ 3h Solution impact	○ Formative: early in project ○ Summative: midway in project
Design Review[a] (SA)	○ 3c Design (process)	○ Formative: (3x) across project
Project Presentation[a] (SA)	○ 3c Design (solution) ○ 3g Communication (oral) ○ 3k Tools (for visual aids)	○ Summative: midway in project; end of project
Written Report[a] (SA)	○ 3b Experimentation ○ 3c Design (meet needs) ○ 3g Communication (written) ○ 3k Tools (for analysis)	○ Summative: midway in project; end of project

[a] Assessment exercises under development, not yet implemented formally

Assessment exercises are constructed in different forms to elicit student responses that match the type of outcome being measured [Stiggins]. For example, an essay is used to probe student's understanding of their personal growth process and achievements. Short answer questions are used to obtain evidence of understanding related to team member contributions to team dynamics. The student responses are scored using a separate rubric for each of the exercises. Rubrics define performance levels on a 5-point scale for performance factors associated with the performance. Table 4 summarizes the assessment exercises by type of assignment and lists performance factors used to score each exercise.

Table 4: Assessment Type and Scoring for Capstone Assessment Exercises

Assessment Exercise	Response	Assessment Score	Performance Factors
Personal Growth	400-500 word essay	○ Personal growth ○ Writing	○ Growth: goals, achievement ○ Writing: mechanics, impact
Professional Practices	400-500 word essay	○ Professional practices ○ Writing	○ Professional: identifying issues, resolving issues ○ Writing: mechanics, impact
Team Member Citizenship	Rating, short answer	○ Team member citizenship	○ Rating member contributions ○ Improving member contributions
Team Process Development	Short answer	○ Team process development	○ Effective process ○ Proposed improvements
Stakeholder Needs	Short answer	○ Stakeholder needs	○ Customer or user ○ Business or financial ○ Technical ○ Society
Project Outcomes	Short response	○ Project outcomes	○ Problem definition ○ Solution envisioned ○ Solution benefits
Solution Specifications	Short response	○ Solution Specifications	○ Functional performance ○ Financial or business ○ Technical feasibility ○ Social, ethical, professional
Design Review	Team meeting	○ Design process	(not defined)
Project Presentation	Team oral presentation	○ Communication ○ Solution feasibility	(not defined)
Written Report	Formal team report	○ Communication ○ Solution quality	○ Communication: mechanics, impact ○ Solution: performance, profitability, feasibility, impact

This assessment system provides balanced emphasis on both student learning and solution development. Counter to capstone courses that focus on one or the other, this course provides students specific definitions of outcomes and assesses their achievement, which gives substance to expectations for both learner and solution development.

Notable Course Achievements
Course achievements of note include those related to the course development and to student accomplishments.

Offering a two-course sequence that includes engineering and business students is significant in a university environment where business students are not required to complete a capstone course and engineering students may have a one-semester capstone course requirement. This has been achieved through alignment of our first course with a university requirement for a capstone general education course. By working with general education program administrators, we have identified social issues content in our course that merits its approval for satisfying the general education capstone requirement. With this approval, engineering and business students may enroll in our first course without adding unnecessary credits to their degree programs.

The second course in our sequence is being accepted as a substitute for engineering students' capstone design course requirement. This approval has required assurances that course learning outcomes include key ABET outcomes typically addressed in capstone design courses: teamwork and design, in particular. The clear definition of outcomes and strong assessment measures used in our course has provided a solid case for accepting this course as a capstone engineering design course.

The development of an integrated entrepreneurship-engineering capstone is also significant, because it serves students with very different backgrounds. Course topics alternate among team, product, and business development topics to provide a common foundation for all students. Pressing students toward self-learning and high performance teams has produced cross-disciplinary knowledge in all members and inter-dependence among members. Only when teams accept the challenge and support one another as a team can they achieve the performance desired. By the end of the second term, essentially every team demonstrates these qualities.

Teams regularly demonstrate very strong accomplishments by the end of the second semester. They produce creative technical products that make solid business sense. They are able to communicate project results and business potential to business and engineering audiences. They are able to articulate deep insights about interrelationships among business and engineering issues. They exhibit justifiable confidence in interactions with others.

Indicators of course success for the 2005-2006 year include:

- One team formed an LLC with their wheel chair product, placed second in the WSU business plan competition, and placed fourth in the national SEED business plan competition
- One team created a workable treadle pump prototype that they tested in Malawi and proved competitive with others available; they also won a special award at the University of Washington business plan competition and raised significant funding for continuation of this project
- One team produced a prototype teaching kit and tested it in 4th and 7th grade science classes, and received acclaim from students and teachers
- All teams were complimented by WSU business plan judges for their strong performances among university-wide competition

- Student’s reflective essays as part of course assessment have documented significant personal growth and new insights related to course outcomes
- Individual students were transformed by their experiences in this capstone design course: attitudes about business relevance to engineering, discoveries about new career paths fitting them, excitement about serving others
- Repeated corporate sponsors of projects remarked about the significant improvement in performance of teams in 2005-2006 over previous year team performances
- Description of the course to industry advisory board and prospective new project sponsors yielded strong encouragement to expand the opportunity to students

Conclusions

The capstone engineering design course described in this paper has produced many different impacts of importance to engineering degree programs. Significant improvements were seen in student preparation and confidence for technological product and business innovation. Participating students from engineering, business, and other disciplines gained appreciation for other disciplines, developed competence to work across disciplines, and broadened their understanding of business development in a global context.

The use of research-based outcomes and assessments strengthened student achievement with respect to both student learning and product development. The clear, well-rounded outcomes forced students outside their narrow focuses. Team interdependence in learning and product development yielded integrated performances at levels uncommon in university courses. Frequent team presentations in varied venues produced strong abilities to communicate with diverse audiences. Use of numerous assessments spread over the duration of the courses kept a variety of learning outcomes before students and stimulated broad learning.

Several indicators have confirmed the success of the entrepreneurial engineering capstone course sequence. Sponsors and others concerned about national competitiveness would like to see this model expanded to serve more students. Scale-up is difficult due to joint teaching, different requirements of each degree program, and management of projects crossing disciplines. Strategies described in this paper may address some of these and other challenges to cross-disciplinary courses. The course sequence presented here offers a successful model for preparing graduates for innovative product and business development in a global environment.

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