The Implementation of Senior Design Capstone Projects Combining Engineering and Business Students

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In order to address complex and multi-disciplinary world problems, it is necessary to create a diverse engineering work force composed of competent and creative individuals prepared to meet current and future global challenges. The entrepreneurial skillset has become increasingly important in this area; the vocational skills that a student learns can be augmented by an understanding of how business operates as well as an appreciation that enterprise skills can be applied within an organization. Traditional university programs lack the teaching methods to turn today's students into innovative and creative leaders who can integrate both the engineering and business skills necessary to succeed in this technology driven global economy. The developed curriculum integrates engineering skills with entrepreneurial creativity by placing engineering and business students on the same projects in the same physical space to facilitate cross-pollination of knowledge in a collaborative learning environment to create technology savvy entrepreneurs. This paper outlines the curriculum framework, a discussion of the resources required, overviews of typical industry projects, a discussion of evaluation criteria, and a discussion of the benefits.

Introduction

"Our world is changing at an accelerated pace and the boundaries between disciplines are blurring. Under these dynamic conditions, we face global challenges at a scale never before seen. The new age of engineering is at the great intersection of left brain and right brain engineering; three core concepts will shape the future: whole-brain engineering, collaboration, and balance."

–Dr. Julio Ottino, Dean of the Robert R. McCormick School of Engineering and Applied Sciences at Northwestern University

The goal of the program was to transform the way engineering students learn through the development and implementation of an interdisciplinary capstone course that involves heavy interaction with industry to develop new products and business plans. The design projects involved the creation of cross-disciplinary design teams comprised of engineering students, business students, engineering faculty, business faculty, entrepreneurs, and professional engineers. The primary objectives included increasing student interest and achievement, enhancing student experience to simulate real world business interactions, stimulating student interest in entrepreneurship and innovation, and increasing faculty member's knowledge.

A cross-functional capstone course is well established in management and business pedagogy, but not as heavily utilized in engineering [Kachra and Schnietz, 2008]. ABET, the primary organization that accredits engineering programs in the US emphasizes the need for engineering courses that build teamwork, communication, and project based skills. An interdisciplinary capstone course aids in building and enhancing these skill sets. This paper provides a framework and the related support structures required for implementing interdisciplinary engineering and business capstone projects.

Need Assessment and Background

The strong need exists to enhance and optimize the current engineering education ecosystem to meet the rapidly changing needs of society in an agile and focused way that is equally open to all members of society. The entrepreneurial skillset has become increasingly important in this area; the vocational skills that a student learns can be augmented by an understanding of how businesses operate as well as an appreciation that entrepreneurial skills can be applied within an organization [Hills and Bull, 2001]. Other research indicates that there is a large 'gap' between 'concept and capital' [Massie and Massie, 2006]; engineers with an entrepreneurial mindset can close this gap within an existing research and development infrastructure or to develop new business ventures.

Engineers are often tasked with creating the next revolutionary device or process, but often times lack knowledge and skills to understand the business processes surrounding the concept. In 2013, a team of engineering education researchers from the University of Tennessee focused on the new roles of engineers for technological innovation and internal entrepreneurship; the team identified that engineers scored higher on tough-mindedness and intrinsic motivation; but lower on assertiveness, conscientiousness, customer service orientation, emotional stability, extraversion, image management, optimism, visionary style, and work drive [Fornaro et al., 2007]. From analyzing the results of the over 80,000 students in the 2013 study, the researchers' conclusions were not encouraging for the new roles of engineers such as entrepreneurship.

Even if engineering graduates choose not to start a new business venture, the entrepreneurial skillset is required within large firms where they often are employed in R&D; this development is seen most desirable by the companies today [Brindley et al., 2009]. Recent research has also concluded that the entrepreneurial skillset will also allow engineering graduates to move into diverse fields, such as medicine, law, or business; hence increasing job opportunities, job satisfaction, and overall quality of life for this group [Engel, 2009]. This program focused on integrating entrepreneurship and new product development education into the current engineering ecosystem. New knowledge was discovered related to how these skills create more qualified graduates. This program formed a novel and cross-disciplinary team of faculty, engineers, entrepreneurs, and lawyers to advance the understanding of engineering education in a meaningful and transformative way that can be easily transferred to other institutions.

Collaborative and Project-Based Learning (PBL) have been shown to increase individual learning through co-construction and personal reflection [Brindley et al., 2009]. Despite research findings that project-based instruction promotes curiosity and improves achievement, the formal classroom continues to be less than conducive to developing these needed skillsets for engineering students at the freshman level [Engel, 2007]. At a time when accreditation requirements and professional licensure examinations have become the metric for student achievement at open-enrollment engineering institutions, instructors often focus on narrow objectives leaving little time to address legitimate student inquiry to build these skillsets at the early stages on one's college studies [Engel, 2009]. As a result, engineering students do not learn how to explore problems without solutions thereby limiting their curiosity and development of skills required by the workplace, including instilling an entrepreneurial mindset. Many engineering students who participated in design activities that nurture collaboration and creativity hold positive beliefs about their school and own competence [Patrick, 2008].

Entrepreneurial design projects have not been widely implemented in the US, but may offer huge promise to create the next generation engineers in terms of whole brain engineering, creativity, and collaboration [Lüthje and Franke, 2003]. If students are to be prepared to meet current and future challenges, engineering students must work effectively in teams to assess needs and to co-create solutions while considering both social and economic implications [Sunthonkanokpong, 2011]. Thus, from a value proposition perspective, providing an educational environment for freshman to senior engineering students that nurture creativity, collaboration, and entrepreneurial design is likely to result in positive life-altering consequences. This research will provide the foundation to better understand and exploit how engineering students learn in dynamic, cross-disciplinary, and opened-ended environments.

Curriculum Framework and Learning Outcomes

Developing the integrated curriculum with all key stakeholders was a fundamental first step in creating the senior design capstone projects that combined engineering and business students. Figure 1 provides a conceptual overview of framework for the implementation of the combined capstone projects.

This framework enhanced industry collaboration as it provides a systematic approach to establish a common meetings space, problem resolution guidelines, addresses technology transfer, and assesses client satisfaction levels. These efforts have progressed to combine engineering and business students on the same projects to foster cross-pollination of skill sets and simulate real world team environments. Advantages of the combined capstone course are that it facilitates a deep as opposed to surface learning and enhances communication skills. As engineers are called upon to work in cross functional teams, the skills learned using this method will place them in a stronger position to be successful as they move into the workforce upon graduation. In this paper, the authors draw upon their experience in the College of Engineering and the College of Business and Innovation integrating the capstone course and senior design clinic into the curriculum.

The learning outcomes for the course were the ABET a-k Student Learning Outcomes (ABET, 2015):

a) Ability to apply knowledge of mathematics (including differential equations and statistics), science and engineering.
b) Ability to design and conduct experiments, as well as make measurements on and interpret data.
c) Ability to design a system, component, or process to meet desired need.

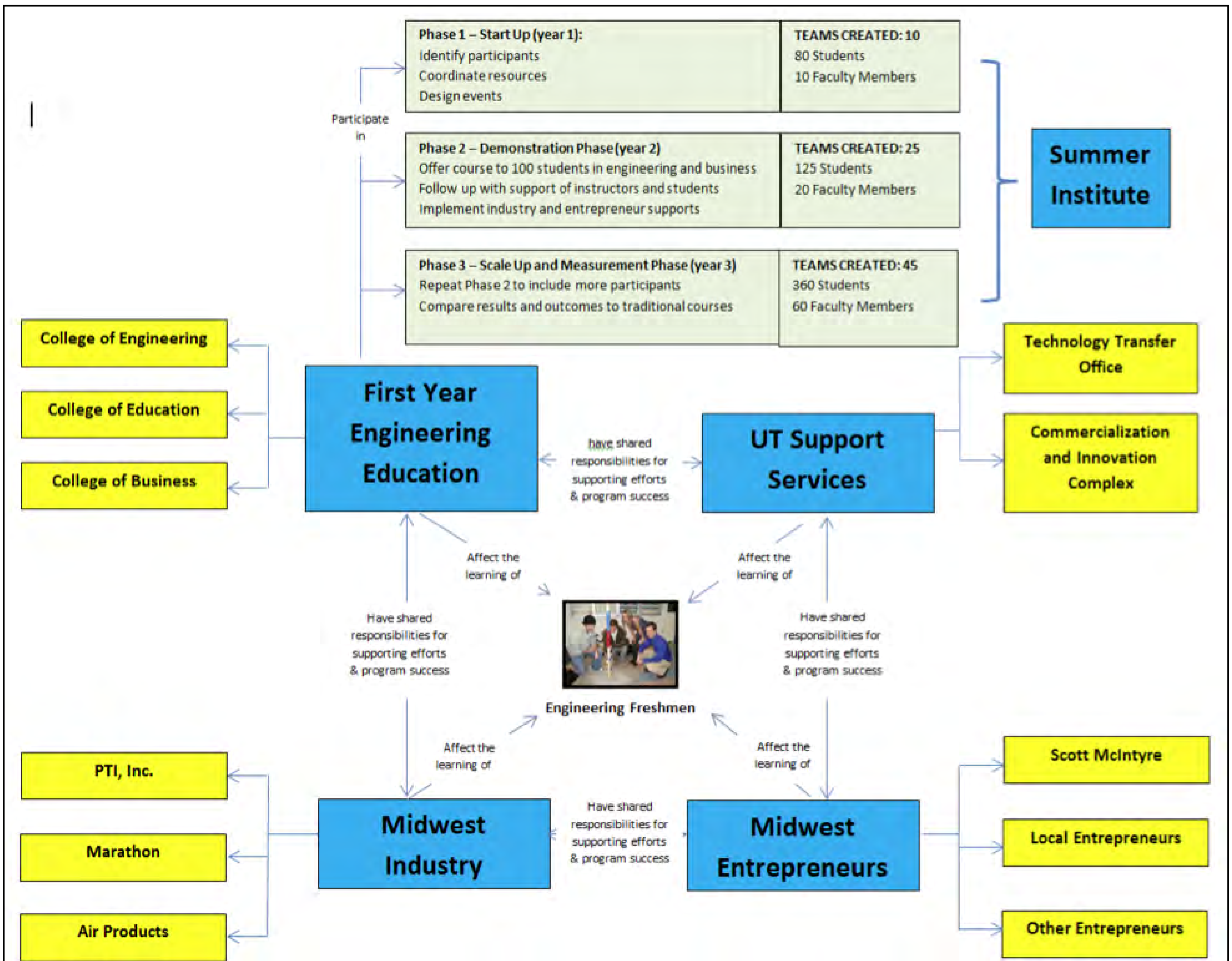

Figure 1: Curriculum Framework

d) Ability to function on multi-disciplinary teams.
e) Ability to identify, formulate, and solve engineering problems.
f) Understanding of professional and ethical responsi bility.
g) Ability to communicate effectively.
h) Broad education necessary to understand the impact of engineering solutions in a global/societal context.
i) A recognition of the need for, and an ability to, en gage in life-long learning.
j) A knowledge of contemporary issues.
k) Ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Resource Requirements

Several resource requirements and planning were needed for the combined senior capstone projects. Faculty members in both the College of Engineering and the College of Business and Innovation were identified and assigned to the combined course. Work space was required for the student teams to meet and build their prototypes. Industry and entrepreneurial advisors were identified and assigned to the project team to assist the students in the design of their prototypes and analysis of their business plans. Potential projects were identified working with industry advisors and faculty. Finally, the University's Technology Transfer Office was contacted to develop protocols, processes, and agreements. Typically, one faculty member serves as Course Director and is in charge of all administrative aspects of the course, including identifying the projects to be conducted by the students. Each group is supervised by a Faculty Advisor (Project Technical Advisor) and a Client Advisor. The Project Technical Advisor and the Client Advisor meet with their groups on a weekly basis.

Resource allocation for the program required strong commitments from the Deans of the College of Engineering and the College of Business. Often times, the expenditure of this level of resources often detract from the success of these programs for two reasons; 1) the excessive number of faculty involved in the program and 2) the excessive time commitment for the faculty involved. The commitment and support from the Deans aided to minimize these detractions. These types of courses and programs are extremely valuable to student learning but in the current environment, at least the engineering colleges, considered inefficient without support from upper administration.

Administration of the Course

The University of Toledo, through its Department of Mechanical Engineering (College of Engineering) and the Department of Management (College of Business) accelerated the formation of new ventures by developing an innovative collaboration involving senior mechanical engineering design students and senior students majoring in entrepreneurship from the College of Business. This collaboration involved merging the two senior capstone courses for each major to create a new combined course. The course focused on synthesizing engineering and business skills with entrepreneurial creativity to transform our students into creative, innovative, and global leaders who understand how to capitalize on technological advances and transform them into business opportunities.

The Senior Design Clinic is a joint collaboration among the Mechanical Engineering Department Senior Design students, faculty and industries. As participants in the clinic, students work in teams using knowledge gained in earlier courses to solve real world design, manufacturing and operational problems relevant to industries. Oral and written communications with participating companies as well as teamwork are stressed. Other topics include design for manufacturing, patents, product liability, safety, ethics, technical report writing, and presentation skills. Industries play a major role in the success of this program by providing an engineering project challenge and technical as well as financial support. As members of the clinic, the industries seek and obtain a solution to a specific engineering project or problem relevant to their organization within a short time. Secure laboratory space is provided for the students and clients that is equipped with computers, fax, phone, hand tools, and dedicated workspace.

The primary purpose of the senior design clinic was to form a partnership between academic and industry and enhance their senior design capstone course experience. Students would take the skills they garnered through their three or more mandatory cooperative education experiences and use them to perform as a consulting team during the senior design clinic experience. The clinic was the administrative and financial side of the academic experience. Course work was delivered by a faculty member whereas the consulting activities were administered by the clinic director. Additionally, students were given parameters in regards to leadership roles, budgetary preparation, peer evaluation, travel expenses and reporting and accountability to their team. All of these expectations prepared the students to enter the work force full time upon graduation.

Class Number	Topic
1	Overview of projects and orientation to class
2	Guest presentations: Machine shop policy and purchasing process
3	Instructor Presentation: Design Process, communication, and teamwork
4	Guest presentations: Business plan development
5	**PROPOSAL PRESENATIONS BY STUDENTS**
6	Guest Lecturer: Entrepreneurship
7	Guest Lecturer: Legal and safety aspects
8	Guest Presentation: Ethics
9	**MID-TERM PRESENTATIONS BY STUDENTS**
10	Guest Lecturer: Technology Transfer
11	Guest Lecturer: Communication training
12	Guest Lecturer: 3D printing and rapid prototyping
13	Guest Lecturer: Business plan canvas and financing
14	No class - team project work
15	Project reviews and preparation for final presentations
16	**FINAL PRESENTATIONS BY STUDENTS**

Table 1: Weekly Schedule

Course Schedule and Weekly Schedule

The course was structured over the 16 week semester and involved outside guest speakers to deliver technical content. Table 1 provides an overview of the concepts taught, requirements, and activities. Teamwork, both leadership and management, are critical components of the course. Ulrich, Smallwood, & Zenger, (1999), discuss leadership functions in terms of engaging customers and stakeholders. The course also emphasized management functions that provide the strategies to efficiently implement a project and that leadership and management are keystones to effective and efficient implementation of a project.

Phase One Implementation and Project Examples

During the first semester of implementation in fall 2013, Phase 1 displayed previously in Figure 1 was implemented. Ten teams of eight students were created (composed of five engineering students and three business students). Each team was assigned one engineering faculty member and one business faculty member as faculty advisors, one industry advisor, and one entrepreneurial advisor. Sample projects from the first semester of implementation included:

- The development of a device and procedure to remove blood clots;
- A development of a power assisted wheelchair;
- The development a universal device to open jars and bottles for individuals with disabilities;
- The development of a process to sort post-consumer plastics for recycling using electromagnetic waves and ferro fluids; and
- The development of an autonomous flying drone to detect and fight forest fires.

Each project involved the development of a prototype and the creation of a business plan over the 16 week semester.

Phase Two Implementation

Phase two implementation during the fall 2014 semester added several new projects combining engineering and business students related to:

- A development of a hands free umbrella device;
- A development of a portable wheelchair van ramp;
- The development of an organ repositioner for prostate radiation;
- The development of a tablet and drink delivery device for a quadriplegic; and
- The development of a detachable and foldable attachment for a manual wheelchair.

Technology Transfer and Intellectual Property

Considering that the end result of the project is a technological project and business plan, students had a tremendous opportunity to learn about technology transfer and intellectual property. The Design Clinic integrated this into the course by dedicating one lecture period to the related issues. A Patent Lawyer from the University's Technology Transfer Department provided a presentation and question/answer session that covered patents, trademarks, commercialization, and entrepreneurship. The Patent Lawyer also discussed the University's role in technology transfer, the evaluation of potential ideas using a standardized process, financial support inside and outside of the University, and legal aspects associated with working with an outside client on a new design [Franchetti et al., 2012].

Typically, three to four projects per semester complete an invention disclosure and initiate the new product evaluation process. To date, one product has been patented via the senior design projects related to autonomous flying drone to detect and fight forest fires.

Assessment of Learning Outcomes and Student's Perspectives

The main purpose of the assessment phase was to compare the achievement of learning outcomes from the previous offering of the capstone course that did not combine engineering and business students versus the new combined version. For consistency, the same questions and assessment processes were utilized for both offerings of the course. Additionally, the same instructor taught both offerings of the course. The achievement of learning outcomes were assessed via a faculty course assessment report (also utilized for ABET Student Learning Outcome assessment), industry partner/client assessment, instructor evaluations of final products, and student questionnaires.

The faculty course report comparison is displayed in Table 2. The previous offering of the course had 64 students enrolled and the combined offering had 80 students enrolled. As displayed in Table 2, average level of achievement increased from the previous offering to the combined offering of the course.

Industry partnership and client assessments were also conducted regarding the quality of the design solution, teamwork, and communication. At the final design presentation, the industry partner or client that worked with each team conducted an interview and review of the final prototype with the design team. Table 3 displays a comparison of the results between the two offerings. The assessments used the following scale: 1 = poor, 2 = below adequate, 3 = adequate level, 4 = high level, and 5 = excellent. As displayed Table 3, the level of achievement increased from the previous offering to the combined offering.

Additionally, instructor evaluations were also conducted to assess the quality of the final prototype, teamwork, and communication based on the following scale: 1 = poor, 2 = below adequate, 3 = adequate level, 4 = high level, and 5 = excellent. Table 4 displays the results. As displayed Table 4, the level of achievement increased from the previous offering to the combined offering.

Finally, student questionnaires were also given at the end of each course to measure the students' perceptions on the quality of the course based on the following scale: 1 =

		Previous Offering		Combined Offering	
Outcome	Assessment Document	Level of Achievement Average	Standard Deviation	Level of Achievement Average	Standard Deviation
a	Midterm and final report scores	0.87	0.065	0.93	0.061
b	Midterm and final report scores	0.87	0.065	0.93	0.061
c	Evaluation of final prototype	0.85	0.071	0.91	0.065
d	Teamwork assessment report	0.82	0.073	0.88	0.069
e	Midterm and final report scores	0.87	0.065	0.93	0.061
f	Ethics assignment	0.91	0.039	0.92	0.043
g	Oral presentation scores	0.88	0.055	0.94	0.054
h	Midterm and final report scores	0.87	0.065	0.93	0.061
i	Midterm and final report scores	0.87	0.065	0.93	0.061
j	Midterm and final report scores	0.87	0.065	0.93	0.061
k	Midterm and final report scores	0.87	0.065	0.93	0.061

Table 2: Faculty Course Report Comparison

	Previous Offering		Combined Offering	
Assessment Type	Level of Achievement Average	Standard Deviation	Level of Achievement Average	Standard Deviation
Quality of design solution	3.9	0.82	4.2	0.90
Teamwork assessment	3.8	0.78	4.3	0.69
Communication assessment	3.9	0.81	4.1	0.65

Table 3: Industry Partner Assessment Comparison

	Previous Offering		Combined Offering	
Assessment Type	Level of Achievement Average	Standard Deviation	Level of Achievement Average	Standard Deviation
Quality of design solution	3.6	0.65	4.0	0.75
Teamwork assessment	3.5	0.51	4.4	0.61
Communication assessment	3.7	0.55	4.4	0.63

Table 4: Faculty Member Assessment Comparison

excellent, 2 = high level, 3 = adequate level, 4 = below adequate, 5 = none or not covered. The overall quality of the original offering of the course received a mean score of 2.5 with a standard deviation of 1.9. The combined offering of the course received a 1.7 with a standard deviation of 0.6. Overall, the faculty members and chairs were satisfied with the results and felt that learning outcomes were met and the students rated combined offering of the course at a higher level.

From a qualitative standpoint, feedback from the students enrolled in the combined offering of the course regarding the quality of the experience in the course was also gathered. This section provides firsthand perspectives from several mechanical engineering and business students that completed the combined capstone course. These comments were taken from end of the semester course evaluations.

"I really enjoyed working with the business students; I learned so much about business plans, market assessments, and meeting customer needs that complemented my technical knowledge".

"As a business student, the combined class helped me to better understand technical aspects and prototyping for new devices; the class also helped me to better communicate with technically oriented engineers and work with a cross-disciplinary team".

"I really liked working with students from non-engineering fields; they brought in a new prospective and really made me think about how well our design will meet the end customer's needs".

Based on feedback from the students, faculty members, and course instructors, the engineering students gained enhanced project management, communication, and business plan skillsets. The business students gained insights into managing technical projects and the engineering design process. Several business students and faculty members commented on gaining an improved understanding of the rapid prototyping process (3D printing) that will allow them to better evaluate new projects and development costs.

Conclusions and Future Directions

The combined course integrated engineering skills with entrepreneurial creativity to facilitate cross-pollination of knowledge in a collaborative learning environment. The goal was to significantly enhance and connect the existing engineering capstone design course and the business capstone course to create 'new age engineers and entrepreneurs' by combining engineering and business students. The combined course tested the feasibility of entrepreneurial design courses to better understand how it might affect student achievement and learning outcomes. Significant potential exists for positive educational, social, and environmental impacts as demonstrated by the comparison of the original offering of the course to the combined offering. From an educational standpoint, the primary objectives included increased student interest and achievement, enhanced student experience to simulate real world business interactions, stimulated student interest in entrepreneurship and innovation, and increased instructor's knowledge. The ultimate goal of the combined course was to address and improve engineering design and entrepreneurship courses in a boundary-spanning manner to shift the paradigm regarding how we educate engineers and prepare them to enter the workforce.

The complex nature of the design team posed some challenges during the design phase. The challenges were somewhat minor and related to team meetings and communication. Specifically, the challenges included finding common meetings times for the business/engineering faculty, determining meeting locations (on the engineering campus or business campus), and the engineering students using too much technical jargon. Although "engineering students using too much technical jargon" is included as a negative aspect of the program, it could be one of the truly strong positives to the learning outcomes of the engineering students. These challenges were overcome by establishing a common meeting team for each group and creating 'ground rules' for communication.

Versus a traditional offering of senior design, the results of the course that combined engineering and business students led to several enhanced outcomes as discussed previously in the Assessment of Learning Outcomes section. The engineering students were able to gain a much deeper understanding of the entire project life cycle from idea generation, financial planning, and long term sales strategies. Under the traditional model, the engineering students primarily focused on applying math and science to create a single prototype that would solve a problem. Under the combined model the engineering students gained a much broader perspective related to solving a larger scale problem, mass production planning/costs, and sales strategies. The business students were able to gain enhanced technical skills and the ability to evaluate technical products. The business students were able to gain firsthand experience related to prototyping, material/manufacturing costs, and the design timelines. Both students groups gained valuable experience working in cross-disciplinary teams and communicating to collaborators outside of their fields of specialty.

Future directions for the course relate to implementing Phases 2 and 3 displayed earlier in Figure 1. Ten pilot projects were conducted in the fall 2013 and 15 conducted in fall 2014.

Through Phases 1 and 2, the team will examine several related research questions throughout the project, which will contribute to the relatively scant literature base on integrated entrepreneurial courses. This project will seek to answer three fundamental questions:

1. Is the combined engineering/business program accomplishing its goals?
2. Is the combined engineering/business program a good way to encourage engineering departments to update their programs to incorporate new teaching methods?
3. Is the combined engineering/business program successful at providing a better engineering education for students?

Based on the assessment of learning outcomes discussed earlier, a preliminary review of these fundamental questions indicates that the combined course is accomplishing the established goals and these new methods provide a better education for engineering students.

The successful implementation of Phase 1 provided insight into the benefits of integrated senior capstone courses. By implementing and analyzing Phases 2 and 3, the faculty team will be able to push the boundaries of integrated capstone courses, answer the research questions, and generate new information to enhance student learning outcomes. Additionally, future projects will include Chemical Engineering, Electrical Engineering, Biotechnical Engineering, Aeronautical Engineering and Physics Engineering; making the program truly multidisciplinary.

References

ABET (2015). Assessment Planning. http://www.abet.org/accreditation/get-accredited-2/assessment-planning/. Retrieved 10/25/2015.

Brindley, J., C. Walti, and Blaschke, L. (2009). Creating Effective Collaborative Learning Groups in an Online Environment. The International Review of Research in Open and Distance Learning. 10, 26-32.

Fornaro, R., Heil, M., and Tharp, A. (2007). Reflections on 10 years of sponsored design projects: Students-clients win!. The Journal of Systems and Software, 80, 35-41.

Engel, S., (2009). How teachers respond to children's inquiry. American Educational Research. 46, 183-202.

Engel, S. (2007). Open Pandora's Box: Curiosity in the Classroom (Sarah Lawrence College Occasional Papers). Sarah Lawrence College, New York

Franchetti, M., Hefzy, M., Pourazady, M., and Smallman, C. "Framework for Implementing Engineering Senior Design Capstone Courses and Design Clinics", Journal of STEM Education, Vol. 13, No. 3, pp. 25-40, 2012.

Frank, M., and Elata, D. (2005). Developing the capacity for engineering systems thinking (CEST) of freshman engineering students. Systems Engineering. 8, 187 – 195.

Hills, W. and Bull, J. (2001) An innovative approach to integrating engineering design: The Newcastle Engineering Design Centre, Engineering Structures, 23, 67-74.

Kachra, A. and Schnietz, K. (2008), The Capstone Strategy Course: What Might Real Integration Look Like?. Journal of Management Education, 32, 81-89.

Lüthje, C., Franke, N. (2003). The 'making' of an entrepreneur: testing a model of entrepreneurial intent among engineering students at MIT. R&D Management. 33, 135-147.

Massie, D. and Massie, C (2006). Framework for Organization and Control of Capstone Design/Build Projects. Journal of STEM Education. 7, 21-29.

Patrick, H., Mantzicopoulos, P., Samarapungavan, A., French, B.F. (2008). Patters for young children's motivation for science and teacher-child relationships. The Journal of Experimental Education. 76, 121-144.

Ulrich, D., Smallwood, N., & Zenger, J., (1999), Building Your Leadership Brand, from On Mission and Leadership, edited by Frances Hasselbein and Rob Johnston, Jossey-Bass, New York, New York.

Sunthonkanokpong, W. (2011) Future global visions of engineering education. Procedia Engineering. 8, 160-164.

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