A Pilot for Integrating Capstone Design with a Two-Semester Innovation & Entrepreneurship Course Sequence

Dr. Keith G. Sheppard, Stevens Institute of Technology (SES)

Dr. Keith G. Sheppard is Associate Dean in the Charles V. Schaefer School of Engineering & Science and a professor in the Department of Chemical Engineering & Material Science. His research interests have included electrochemical aspects of materials synthesis and environmental degradation of materials. His education in the U.K. included B.Sc. (University of Leeds) and Ph.D. (University of Birmingham) degrees in Metallurgy and a Diploma in Industrial Administration (Aston University). He was the recipient of the Henry Morton Distinguished Teaching Professor Award in 2009. As Associate Dean, Prof. Sheppard has had a leading role in the development of the undergraduate engineering curriculum at Stevens, including innovations in design education and initiatives to include entrepreneurship, sustainability and global competency for undergraduate students.

Prof. Christos Christodoulatos, Stevens Institute of Technology (SES)

Dr. Christos Christodoulatos is Vice Provost for Innovation and Entrepreneurship at Stevens Institute of Technology. The Office of Innovation and Entrepreneurship (OIE) has the mandate to modernize the technology transfer process and design educational and research programs that bring the concepts of innovation and entrepreneurship into the classroom and the research laboratory. Dr. Christodoulatos is leading the implementation of academic entrepreneurship through the creation of innovative curricula and overseeing the commercialization of the Institute's intellectual property. He has been teaching and performing research since 1988 and has managed over a hundred and fifty major research projects exceeding $30M. Dr. Christodoulatos has developed and delivered entrepreneurship curricula and specialized innovation and entrepreneurship workshops for faculty, administration and technical entrepreneurs in Malaysia, Brunei and Taiwan. He is a founding member of two start-up companies for the commercialization of environmental technology. He holds several patents in water and air treatment technology and has authored over 150 articles in professional journals, conference proceedings, and handbooks. He has chaired a number of international conferences, he is a member of several professional organizations, a reviewer to several journals and serves as a consultant to government and private organizations. He holds a BE and ME in Chemical Engineering from City College of the City University of New York, and a Ph.D. in Environmental Engineering from Stevens Institute of Technology.

Dr. Kate D. Abel, Stevens Institute of Technology (SES)

Kate Abel serves as the as the Director of the Bachelor of Engineering in Engineering Management Program in the School of Systems and Enterprises at Stevens Institute of Technology. She holds a Ph.D. in Technology Management and Applied Psychology. She has held several professional service positions including the President of the Engineering Management Division of the American Society for Engineering Education and the President of Epsilon Mu Eta, the Engineering Management Honor Society. She teaches courses in Total Quality Management, Engineering Economics, Entrepreneurial Analysis of Engineering Design, Statistics for Engineering Managers, Management of Engineering and Technology, and Senior Design. Her research areas include knowledge engineering, as well as, knowledge and information management. She has been published several times including chapters in the books Eshbach's Handbook of Engineering Fundamentals and Engineering Economic Analysis; in journals such as the Engineering Management Journal and the Journal of Engineering Education; and several conference proceedings. She is a member of the Board of Advisors at West Point for the Department of Systems Engineering. She is also a member of several professional societies including ASEE, ASEM, ASME, and EMH.

Dr. Leslie R Brunell P.E., Stevens Institute of Technology (School of Engineering and Science)
Ms. Sandra V. Furnbach P.E., Stevens Institute of Technology
Dr. Vikki Hazelwood, Stevens Institute of Technology (SES)

Dr. Vikki Hazelwood is an expert in Translational Medicine. She arrived at Stevens upon having served 25 years in industry. Most recently she held executive positions in Sales and Business Development for

Medical Device companies where she honed her expertise in commercial development and new product launches for medical devices. Her experience includes many years of clinical interface with surgeons and NY metro area hospitals, as well as successful business collaboration with senior decision makers of global medical device companies.

In her earlier years, she served in product development and project management roles for chemical and biochemical process systems, i.e. capital equipment used to manufacture pharmaceuticals, medical products, and other specialty chemicals. Throughout her career, she has proven that she has tactical skills and expertise to match her unique and creative strategic insights.

Since arriving at Stevens in 2004, Dr. Hazelwood has led a grass roots effort to create and implement an environment of excitement, creativity, and entrepreneurship among Biomedical Engineering researchers. She has created a lab for Translational Research in Medicine, which, in addition to having successfully launched a start-up company, has spawned several patents and patent applications, all of which have intimately engaged collaborative teams including physicians, industry experts, technical experts, and students throughout the process.

Dr. Hazelwood has successfully brought entrepreneurship into the academic research and educational process, and, in just 3 years, has lead the development of a venture capital backed start-up company, SPOC Inc.—a point of care product for pain management—for which she served as President and CEO, and her student founders are co-inventors and full time employees. The company has received $1MM in extramural (venture institutional) financial backing and has received 510K clearance from the FDA.

Researchers who work in Dr. Hazelwood's lab are asked to help develop a solution to an unmet medical need, and that solution is to be brought from inception through to clinical use within a 3 to 5 year period. Dr. Hazelwood's focus is on problems in public health; her teams work on projects that will address unmet needs in public health, and will contribute to reducing costs and improving clinical outcomes. As physiologic systems engineers, the engineering research teams work in close collaboration with physicians and other expert clinicians to develop technologies that better recognize and interpret physiologic function. Many such projects are focused upon the goal to more accurately diagnose injury or disease, and improve outcome efficacies. Dr. Hazelwood has written a book (Hazelwood, Vikki, Do College Students Benefit from School Required Activity. Saarbrücken, Germany, VDM Publishing, 2008), and has been invited to speak at Grand Rounds (NYMC) and also as Plenary Lecturer at the Biomedical Engineering Summit to share her work.

Dr. Hazelwood's recent collaborations have resulted in valuable and novel public health solutions. Her work has spawned 7 patent applications, which include her undergraduate students as authors. These projects included doctors and clinical teams from Hackensack University Medical Center, New York Medical College, University of Medicine and Dentistry New Jersey, and New York University. Dr. Hazelwood has served in roles as Principal Investigator, co-PI, Sponsor and Advisor to human clinical trials that have been conducted at these institutions to support the commercial development of technologies conceived and developed in her labs. She also holds a research position in the Department of Emergency Medicine at HackensackUMC.

Dr. Hazelwood's students have proven their excellence by having earned 5 US patents based upon their senior design projects, with several more patent applications in the pipeline. In addition, they have earned regional and national acclaim for their projects.

Dr. Kishore Pochiraju, Stevens Institute of Technology (SES)

Kishore Pochiraju is an Associate Professor in the Mechanical Engineering department and also the Director of the IDEaS program at Stevens Institute of Technology, Hoboken, NJ. He received his PhD in 1993 from Drexel University and joined Stevens after working as a postdoctoral fellow at the University of Delaware. His expertise spans product design, advanced manufacturing, materials insertion and knowledge-based systems integration. His current externally-funded research is on the design of real-time electro-mechanical robotic systems, high-temperature materials and micro-/nano-scale devices. He edited one book and authored 3 book chapters and nearly 125 journal and conference proceedings papers. He is a member of ASME, IEEE and American Society for Composites (ASC).

Mr. Eirik Hole, Stevens Institute of Technology (SSE)
Prof. Bruce McNair, Stevens Institute of Technology (SES)

Bruce McNair has been a Distinguished Service Professor in the Electrical and Computer Engineering faculty at Stevens Institute of Technology since 2002. During that time, he has been responsible for conducting the ECE two-semester capstone Senior Design course, advising a majority of the project groups as well as teaching several other undergraduate and graduate courses. Previously, he spent 24 years at AT&T Bell Labs/AT&T Labs-Research plus several years at the US Army Electronics Command at Fort Monmouth and ITT Defense Communications Division.

Prof. Thomas G. Lechler, Stevens Institute of Technology

Dr. Thomas G. Lechler is Associate Professor at the Howe School, Stevens Institute of Technology. His research interests focus on value creation through innovation with particular emphasis on the management of projects and the recognition and exploitation of business opportunities. He regularly presents his work at leading international research conferences. His work is published in the leading technology management journals and he has published four books. His research has received several awards. In 1999 at the Rent 13 Conference in London he received the best Paper Award. In 2010 he received the PMI Project Management Journal Paper of the Year Award. He has received several research grants from NSF and from other funding organizations. From 2003-2005 he was appointed NASA research fellow in project management.

A Pilot for Integrating Capstone Design with a Two-Semester Innovation & Entrepreneurship Course Sequence

Abstract

A pilot program at Stevens Institute of Technology is described to integrate senior-year capstone engineering design with a two-semester course sequence that addresses innovation and entrepreneurship (I&E), these topics representing an evolving core thread in the curriculum to address the demands of 21st Century careers. The pilot has specifically addressed the challenges of doing this with multidisciplinary design projects. The pilot team comprised experienced capstone design coordinators from several disciplines together with faculty members who teach entrepreneurship. Separate multidisciplinary sections of the two-semester senior capstone design course had a lead faculty coordinator with other faculty advisers as consultants where appropriate from the disciplines involved in each of the projects. The two-course I&E sequence was integrated with the capstone design courses. Most importantly the senior project teams were scheduled into an I&E course section as a team to facilitate the capstone project integration with these courses. The courses strived to directly develop the relevant I&E concepts in the context of each design project. The paper discusses the significant challenges in implementing a coordinated approach, especially in the multidisciplinary context, including the need to meet program capstone outcomes and more recently achieve consistency across core outcomes in addition to those that are program specific. Student and faculty assessment of the pilot to date show good progress made but challenges remaining. A significant feature of this initiative is its goal to scale the approach to all engineering programs at the university.

Introduction

Engineering educators are challenged to prepare their students with the knowledge and competencies that will support success both in the immediate post-graduation period and also as the foundation for careers in the rapidly changing global environment in which these will be pursued. It is not sufficient to educate engineers just to be technically competent. Engineering curricula and the accreditation criteria for engineering programs have evolved to reflect this reality by demanding that an array of non-technical and contextual competences be addressed. One critical contextual domain is an understanding of the business context of engineering. For success in 21st Century careers students need more than just an appreciation of the business context, they need to understand and be able to contribute effectively to value generation, whether that be for the products or services of a company, to establish a new venture or increasingly for themselves as they compete to demonstrate their value in an increasingly international marketplace for technical skills. The context is one in which entrepreneurial thinking and competences will be a key success factor. In response we are seeing increasingly around the nation the inclusion of entrepreneurship into engineering curricula through various approaches, either directly through courses or modules, or integrated into a course or by offering a minor for a subset of motivated students.

Byers & others[1] have recently described this trend, its motivators and the approaches being taken by engineering programs. They point to student interest as a significant feature, referring for

example to research by Duval-Couetil[2] & others who have shown that 70% of engineering senior students surveyed agreed that entrepreneurship education would broaden their career prospects and choices. Although it was also noted that two thirds of the students surveyed intended to work for medium or large companies. It was further found that "those who had taken one or more entrepreneurship courses showed significantly higher entrepreneurial self-efficacy on a number of measures".

The growth of entrepreneurship programs in engineering undergraduate education has been studied by Shartrand & others [3] finding that "the vast majority of programs were labeled as minors, concentrations or certificates" rather than integrated into the core curriculum. This research has also provided detailed categorization of the models being implemented to provide a "landscape" by clustering types of opportunities and the perspective by which they are taught[4]. Much of the delivery of entrepreneurship education is via courses, however it is argued by Neck[5] & others that these courses highlight process and an abstraction more akin to teaching science rather than developing students to think entrepreneurially, to embrace situations with incomplete information and develop the creativity and other traits needed for success. They point to design-based learning, reflective practice, serious games and simulations, and actually starting a business as the pedagogy to address the method rather than just the content needed for effective entrepreneurial education.

There are programs that have reported efforts to couple entrepreneurship to the senior capstone as context. Brouwer & others at Calvin[6] describe how they try to develop an entrepreneurial mindset through coupling a 2-credit Business of Engineering course in the Fall of senior year to the 2-semester senior capstone, with the linkage through a final project in the business course being a business plan for the capstone project. They also include entrepreneurship-related content in some capstone course lectures. The Calvin program targets all engineering seniors in a small program of approximately 65 graduates per year. More typically programs are not applied to all engineering seniors in the capstone. Ochs & others at Lehigh [7] describe coupling an entrepreneurship minor to the capstone by which students taking the minor work in cross-disciplinary teams in an Integrated Product Development (IPD) approach on projects that both satisfy the 2-semester practicum of the minor and their engineering capstone course requirements. The important role of Professors of the Practice in making this work is noted. Porter & Morgan of Texas A&M[8] have provided other examples in the literature of the types of approaches to incorporate entrepreneurship that will not be repeated here. The A&M initiative is specific to certain programs and focuses on developing the capstone project at completion along two routes to commercialization, either as a new venture or as a licensing opportunity, with business school students participating to assist this focus.

At Stevens Institute of Technology there has been for many years an institutional commitment to creating a more entrepreneurial culture on campus for both faculty and students. This was addressed in the core engineering curriculum through course elements in the sequence of design courses and also through design projects, summer research opportunities, competitions, etc[9]. Later this evolved to include a core seventh semester course with a significant business and entrepreneurship content. In a core curriculum revision in 2005, entrepreneurship was added as an educational outcome for all engineering programs in addition to those that align with ABET outcomes a through k. An entrepreneurship minor was added in 2007 that is available to any

engineering student. In 2014 a 2-credit Introduction to Innovation & Entrepreneurial Thinking course was added to the core engineering curriculum for all students in the second semester of their Freshman year.

Review of the progress towards developing the desired I&E competencies of students, including from student assessment, input of the faculty involved and by engagement with external stakeholders, including program advisory boards, indicated that in addition to the elements described above there was a need to create greater context for and stronger coupling of entrepreneurship to the core engineering curriculum. The capstone two-semester senior design projects were judged, by a committee charged to provide a response, to be an important vehicle to achieve this goal. This decision aligns with the design-based pedagogy argument of Neck et al.[5] that was noted above. This use of the capstone represented a natural evolution as some of the capstone faculty advisers were already making this coupling with the teams they advised.

A pilot program was established to explore the integration with the capstone of a revised version of the seventh semester business & entrepreneurship course by spreading the entrepreneurship course over both semesters of senior year and teaching it with the individual capstone projects as the basis, integrating both the capstone and entrepreneurship course workflows and deliverables. This pilot also prompted a review of the manner in which the senior capstone courses of all engineering programs were managed, with the goal to move to more uniformity in workflow, deliverables and assessments and hence assurance of outcomes across programs. In this context, the pilot targeted multi-disciplinary projects as both the greatest challenge to implementation, but also because the goal is for such projects to become the primary mode for the capstone projects in the future, reflective of the reality of engineering practice. The progress of the initial phase of this pilot was reported previously[10] and we now provide an update following expansion and revision based on assessment.

Pilot Program Context

Stevens Institute of Technology has 9 engineering programs and had an entering Freshman class size across all engineering programs of 523 students in Fall 2014. The senior-year capstone is a two-semester course sequence awarded three credits per semester with an expected one full day per week commitment. Traditionally each program had established their own requirements for the senior capstone within the general credit framework and responsive to disciplinary accreditation requirements. A limited number of multidisciplinary projects had been conducted each year with arrangements made on advising and student deliverables/assessment on a per project basis, not following a standard template.

Organization of the Pilot

Phase 1

Capstone senior design courses

In Phase 1 of the pilot the healthcare domain was addressed and then expanded to include energy. The objective was to add to the technical outcomes of the capstone by also fostering innovation and entrepreneurial thinking while also developing associated competences in teaming, communication, leadership, strategy, identifying and addressing markets and customers, and the development of relevant business concepts.

Figure 1 *Outline of coverage of design and I&E elements within the senior capstone design courses and concurrent Senior Innovation courses over the Fall and Spring of senior year.*

Senior Design				**Senior Innovation**
Capstone Technical Elements *(abbreviated)*	***Capstone I&E Elements***			***Lab: Skills development w Theory*** *(summary)*
Project Identification	Market Research	__E423X (3 credits)	TG 403 (2 credits)	Elements of Project Management
Problem Definition	Mission Statement			- Mission Statement
	Practice (organization and presentation skills)			- Customer Need Analysis
Formal Proposal				- Scope Statement (WBS)
Project Review Meeting				- Project schedule/resource planning
	Intellectual Property			Intellectual Property
	Confidential Team Assessments			Business Model to Business Plan - intro
	Procurement			Project Presentation
Execution Plan				
	Expediting	__E424X (3 credits)	TG 404 (1 credit)	
	Writing a Scientific Abstract			Developing a Business Model
	Writing a Test Report			
PRM (parts and build)				Market Analysis
	Elements a Business Model			
				Value Proposition
	Designing a Poster			
				Economics of a Venture
	Write Invention Disclosure			Writing a Business Plan
PRM (functional testing)				
	Final Project Reporting			Elevator Pitch Skills
	Exhibition Skills			
Final Report/ Senior Day	Senior Projects Expo			Elevator Pitch Competition

The pilot was initiated in Fall 2011 with 20 students with projects only in the healthcare domain all led by the biomedical engineering capstone coordinator supported by disciplinary faculty advisers as needed. It was expanded in 2012 to approx. 50 students in two domains; healthcare and energy with an additional coordinator running the energy domain projects after having shadowed the first implementation. It was further expanded in Fall 2013 to 130 students in three domains: healthcare, energy and robotics with a third coordinator engaged to oversee the robotics projects, again having shadowed the prior activities.

Senior Innovation Course

The I&E course referred to above was given the name Senior Innovation and for the pilot students it replaced the core 3-credit Business & Entrepreneurship lecture course that they would have normally taken in Fall of senior year. The latter included some significant elements of entrepreneurship but addressed them in a didactic manner rather than through the context of the senior project. It is this context that is at the heart of the new approach, coupled to the goal of having the Senior Innovation course closely integrated with the concurrent design course on key topics and deliverables. The other key change was that the 3-credits were split over the Fall and Spring semesters to allow the Senior Innovation course to be coupled over the full academic year of the senior project. In Phase 1 this was done with a 50:50 split of the credits. In Phase 2 it was decided that the integration and workload were better served by having two credits in the Fall and one credit in the Spring.

In Figure 1 is seen three columns of elements. Not all elements are shown. The first two columns are associated with the pilot senior design courses shown as E 423X for Fall and E 424X for Spring, each 3 credits. The first column has the technical elements traditionally associated with the senior project, the second column shows the I&E elements that are addressed within the senior design courses in the projects and their deliverables while leaning on the Senior Innovation course for their concurrent content development. The Senior Innovation course is labeled TG 403 for Fall and TG 404 for Spring.

Student Feedback on Phase 1 Pilot

The students were surveyed to provide their feedback during Phase 1.

On the positive side the students appreciated many of the key elements targeted in the pilot including in general the integration of the Senior Innovation coursework with the senior capstone design course. They saw the multidisciplinary design projects as broadening perspective beyond their major as did the inclusion of the I&E elements in the design courses and Senior Innovation. The latter they saw as useful to their projects for the most part. The students overall gave a strong endorsement of the pilot with 95% indicating that they would recommend it.

Concerns were largely with the degree of communication between the design course and the Senior Innovation course instructors, and with the coordination of these courses. The criticisms were most explicit about some elements being disconnected or too late to be of value to the project. Some students did not understand the value of some deliverables to their project. Working in a multidisciplinary team and project was a concern for some students due to the additional challenges they experienced compared to their perception of those they would have faced on a disciplinary project and team.

It should be noted that the Phase 1 pilot required all projects to generate a patent disclosure and produce a short "pitch" presentation typical of those expected when seeking venture funding. A number of the disclosures resulted in provisional patent filings by the university.

Faculty Feedback on Phase 1 Pilot

The development team met regularly to try to achieve the desired coordination both across the design projects and between the design and Senior Innovation courses. In reviewing Phase 1 they made a set of recommendations that included ones that address issues with the teaching/management of capstone design in general:

- Capstone (and other) design courses must be under the supervision of faculty with significant and relevant design experience to be effective. This is often not the case in a research university. The transition to a Professor of Design (of the Practice) (POD) model was strongly advocated. The POD should be the primary agent for generating design projects interfacing with the client/sponsor to understand needs and manage expectations and work with the disciplinary faculty advisers who would support each project. The POD would coordinate a number of projects in a domain. The POD should be a full-time appointment without other teaching duties.
- Common capstone course scheduling across all engineering programs is needed to support multidisciplinary projects. (this scheduling was achieved starting with the 2013/14 academic year).
- A common set of content knowledge and project requirements must be included in all capstone courses to ensure core outcomes are met, especially on the "soft skills". Disciplinary engineering programs can supplement with program-specific requirements. The core set may be facilitated by expert faculty teaching common classes. The common set of requirements must be required and assessed for all projects.

Phase 2

Changes made in response to Phase 1

Phase 2 built on the experience and feedback of Phase 1. In the Fall of 2014 the program was expanded to approx. 240 students from 6 engineering programs. For the 2014/5 year, in addition to the multidisciplinary projects, several engineering programs adopted the pilot format for their disciplinary capstone projects. A working goal was full implementation of the paradigm embodied in the pilot across all engineering programs (approx. 500 students) in 2015/16.

In Phase 1 of the pilot there was only one section of the Senior Innovation courses (TG 403 Fall/TG 404 Spring) but that was expanded to six sections in Phase 2 with multiple instructors. The syllabus for both TG 403 & TG 404 were also revised based on the feedback of Phase 1. In concert, the management, content and outcomes of the capstone senior design courses across the engineering programs of the university were also reviewed by an expanded development team comprised of the senior design coordinators from several more engineering programs and two faculty members involved in organizing and teaching the Senior Innovation courses.

It was clear to the team that if the pilot was to be scaled up to meet the goal of being implemented across all engineering programs of the university, it was necessary to address some significant issues related to the capstone structure and management. In the pilot there had been an ability to maintain a fairly rigid workflow across design groups and sections even when distributed into the three domains under three coordinators, although with some lessening of this

control as the pilot grew from one to three coordinators in disparate domains. This fully prescriptive workflow and deliverables was considered to be a barrier to engagement of all programs, but it was desired to maintain a core template to ensure some level of uniformity in outcomes and assessment for all programs, both with multidisciplinary and disciplinary senior capstone projects.

A particular concern in broader application of the approach across all engineering programs was the inclusion of projects and disciplines that do not lend themselves to a product or service where there is an obvious entrepreneurial link apparent to the students when trying to link the project to content in Senior Innovation and associated deliverables. One example is civil engineering where the projects may have no obvious entrepreneurship link, such as a major infrastructure project, and is a field where engineers typically are not working in a context that has new product or process creation. It is for this reason that the project teams need to be assigned to a Senior Innovation section led by a faculty member who can make the right connections, so that the students can appreciate the entrepreneurial approach in a less obvious context and also deliver appropriate content to their project to meet the needs of both courses without being discouraged.

It was therefore agreed to adopt a broadly aligned workflow and deliverables across all programs and projects in the Phase 2 pilot while still providing flexibility for programs to include their own requirements. One key mechanism to maintain alignment, both across programs and projects and to help the integration with the Senior Innovation courses, was to use a Senior Projects report template required of all groups with major milestones and associated assessments with credit. Deliverables into the report, which is built over the two semesters of the capstone, include items that are developed within the Senior Innovations courses in association with the individual projects. As previously described, the Senior Innovations courses use the capstone projects as the basis for teaching in a workshop rather than didactic format.

Table 1 shows how the capstone design course workflow is integrated with the Senior Innovation course content over the two semesters for Phase 2 and the milestones. The milestones are included in the Senior Design Report template with the goal that, while exact timing may vary between programs and projects, all milestones will be addressed with assessments that carry the same value and form to ensure multidisciplinary projects do not suffer from varying expectations form each of the disciplines involved, something that has handicapped multidisciplinary projects in the past. The goal is to also use common assessments where they make sense, especially for non-disciplinary outcomes in both the design and innovation courses, such as for teaming, communications etc.

Phase 2 results

The first semester of the Phase 2 pilot program was recently completed. It is too early to assess the impact of the changes on the senior projects' course workflow relative to the goals across all projects and programs. Student assessment for the capstone course have not yet been analyzed. We have some early indication that we have made some progress towards meeting the template-based goals. We are also aware that some projects started later than desired due to the problem of not having the project defined before the Fall semester started. This is well recognized by the team as a challenge that has to be solved to be able to consistently meet the goals of the program.

The end-of-semester student assessments for the Fall 2014 Senior Innovation (403) course have been examined. Two ongoing concerns of the students expressed in comments are the coordination between senior design and senior innovation, although we have reason to believe this has improved significantly from Phase 1 based on anecdotal input from the senior design coordinators.

Table 1 Roadmap for Pilot Capstone Sections in Phase 2

Timeline	Senior Design (423/424)	Senior Innovation (403/404)
Phase I (Define)	Design Requirements	Mission Statement / Teaming
	Applicable Codes, Standards, Regulations	Stakeholders & Needs
		Needs Analysis
Early October	**Milestone #1: Customers, Needs, Requirements, Needs-Requirements Mapping**	
Phase II (Innovate)	Concept Generation	Project Schedule (423+424/403+404)
	Design Evaluation Frameworks: with Modeling, Testing, Prototyping	Lean Canvas Business Plan
Mid November	**Milestone #2: Project Plan, Concepts, Concept Selection, Analysis and Testing Plan**	
Phase III (Design)	Design – Analysis – Redesign Loop using simulations and prototypes	Competitive Intelligence
		Financial Analysis
Late January	**Milestone #3: Design Performance and Cost Review with Alpha^{+} Prototype Demonstration**	
Phase IV (Optimize & Demo)	Design Optimization and Prototype Refinement (More design loops)	Intellectual Property Evaluation
		Pitch Presentation preparations
Last Wednesday of March	**Milestone #4: Beta Demonstration^{++} of Optimized Design**	
Phase V (Document)	Design Documentation, Design rationale, BOM and all specifications	Invention disclosures and Innovation Expo preparation
May – Final Week	**Milestone #5: Final report submission, Innovation Expo.**	

$^{+}$Alpha demonstration: Show all the components and sub-systems and how they fit together. System integration is not necessary but functionality of all individual sub-systems must be demonstrated.
$^{++}$Beta Demonstration: All sub-systems must be integrated and the system must be fully functional. The team must be able to demonstrate the operations of the design in realistic user environments.

The other ongoing concern of students is the one already noted above, namely the relevance of entrepreneurship to certain majors. This will be a continuing challenge with some students and majors but one we expect will be assisted by the recent introduction of the Freshmen year

Introduction to Innovation & Entrepreneurial Thinking course, which can set the backdrop of why entrepreneurship can have relevance in the myriad of contexts that the students may find themselves in on graduation.

We have not yet executed on the strong proposal of the development team coming out of Phase 1 to have all senior projects overseen by Professors of Design. We have several faculty members who are transitioning to this full-time role and a commitment from the Provost to support this full transition. However, this requires not only significant funding, but an equally challenging search to hire the individuals with the requisite design background and teaching competences across the range of engineering programs where the gaps exist.

Summary and Conclusions

We have established a significant pilot program to integrate a two-semester innovation & entrepreneurship course sequence with the senior capstone design courses with a particular focus on doing this in the challenging context of multidisciplinary design projects. This pilot was expanded over several years from a small cohort engaged in a single topical domain, namely healthcare, where close control could be maintained by a very experienced coordinator with strong industry experience and connections. It has been expanded to embrace several new domains and faced the demands created by meeting disciplinary engineering program needs while creating an effective multidisciplinary project and integrating entrepreneurship elements that may not have obvious relevance to all students and projects. In further scaling up with a goal to have the approach adopted by all engineering programs for both multidisciplinary and disciplinary programs, we have created a common workflow and deliverables that retain sufficient flexibility to serve all constituencies while assuring a uniformity of outcomes across projects and programs. The scale up has brought new challenges, especially ones unsurprisingly associated with needing to coordinate many design advisers and entrepreneurship instructors in the two integrated course sequences. It has also not yet met expectations for the true integration that is desired. A comprehensive review following assessment of the current first implementation of the Phase 2 scale up will determine if the program is ready for full scale up and the further changes needed to make it happen.

Bibliography

1. Byers, T., Seelig, T., Sheppard, S., and Weilerstein , P., “Entrepreneurship: Its Role in Engineering Education”, The Bridge, Vol. 43, No. 2, Summer 2013, National Academy of Engineering (ISSN 0737-6728)
2. Duval-Couetil, N., Reed-Rhoads, T., and Haghighi, S., “Engineering Students and Entrepreneurship Education: Involvement, Attitudes and Outcomes”, International Journal of Engineering Education, Vol. 28, No. 2, pp. 425–4.
3. Shartrand, A., Weilerstein, P., Besterfield-Sacre, M., and Golding, K., “Technology Entrepreneurship Programs in U.S. Engineering Schools: An Analysis of Programs at the Undergraduate Level” (AC2010-666), Paper 2012-666, Proceedings of the ASEE Annual Conference, 2010.
4. Besterfield-Sacre, M., Ozaltin, N., Shartrand, A., Shuman, L., and Weilerstein, P., “Understanding the Technical Entrepreneurship Landscape in Engineering Education”, Paper 2011-1729, Proceedings of the ASEE Annual Conference, 2007.

5. Neck, H and Greene, P., “Entrepreneurship Education: Known World and New Frontiers”, Journal of Small Business Management, 2011, 49(1), 55-70, cited in ref. 1.
6. Brouwer, R., Sykes, A. and Steven H. VanderLeest, S., “Entrepreneurial Mindset Development in a Senior Design/Capstone Course”, Paper 2011-2462, Proceedings of the ASEE Annual Conference, 2011.
7. Ochs, J, Lennon, G., Watkins, T. and Mitchell, G., “Comprehensive Model for Integrating Entrepreneurship Education and Capstone Projects While Exceeding ABET Requirements”, Paper 2006-1330, Proceedings of the ASEE Annual Conference, 2006.
8. Porter, J. and Morgan, J., “Engineering Entrepreneurship Educational Experience (E4) Initiative: A new Model for Success”, Paper 2007-1950, Proceedings of the ASEE Annual Conference, 2007.
9. Sheppard, K., Boesch, G. and Mihalasky, J., “The Synergistic Roles of a Supportive Institutional Environment, Curriculum Development and a Student-friendly Business Incubator in Developing Engineering Students with an Entrepreneurial Orientation”, Session 2793, Proceedings of the ASEE Annual Conference, 2003.
10. Christodoulatos, C., Lechler, T., Furnbach, S., Hazelwood, V, “Key challenges in Establishing an Entrepreneurial Culture in an Academic Environment-A Case Study”, Technology and Innovation, Vol. 14 pp. 387-401, 2012.