
AC 2011-756: INTEGRATION OF ENTREPRENEURSHIP EDUCATION INTO A BIOENGINEERING CAPSTONE DESIGN CLASS

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Integration of Entrepreneurship Education into a Bioengineering Capstone Design Class

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abstract

This paper presents a template for integrating entrepreneurship educational objectives into a two-semester multidisciplinary capstone design course that engages bioengineering students with business, science and engineering majors to collaboratively create a valuable technological solution (or product) with business potential. Bioengineering seniors enroll in this class for their senior design experience.

An Integrated Design Engineering Assessment and Learning System (IDEALS) is utilized throughout the course to facilitate and assess learning outcomes. IDEALS instructional materials and assessments are structured to provide a general introduction to engineering in today's world. The following are the learning outcomes for the class:

1. Dispositions toward increased **confidence and mindset** to recognize, evaluate and move toward opportunities.
2. Abilities to apply and defend **business development processes** to create a business concept for an envisioned solution that offers potential for a sustainable business investment.
3. Abilities to prepare and critically **read financial documents**, including a balance sheet, income statement, cash flow analysis and break even analysis.
4. Abilities to prepare to seek or **obtain sources of capital** applying knowledge about requirements and pros and cons of different sources of capital.
5. Abilities to apply knowledge about intellectual property to strategically **create barriers** to entry for competitors.
6. Abilities to plan and **manage a design project** to complete specified deliverables within allotted time and budget.
7. Abilities to organize, improve, and contribute effectively to a **multidisciplinary project team**.
8. Abilities to access, learn, process, and demonstrate **knowledge competence** to advance a team-based entrepreneurial engineering project.
9. Abilities to explain and demonstrate ethical and **professional responsibility** in the context of team interactions, class assignments, client interactions, and professional norms.
10. Abilities to **communicate** effectively in written and oral forms to teammates, project advisors, technical experts, and business investors; ability to accurately document learning, ideas, and achievements.
11. Abilities to apply and defend **problem scoping** and **concept generation** (design) processes to create a solution concept aligned with important stakeholder needs.

12. Abilities to evaluate social, economic, legal, and other **conditions that impact success** of the technological product locally and globally.
13. Abilities to **evaluate and explain performance** of solutions in the context of established technical specifications.
14. Abilities to deliver **project products** (design solution and business plan) judged credible by clients and others within the engineering and business professions.

This capstone design course sequence has emerged from a decade of cross-college collaboration and refinement. Results are evidenced by greater entrepreneurial competencies of students, more business-ready technological products, and more substantive relationships with collaborators. Increasingly, the courses are managed to emulate business practice and operate on a rapid development cycle. This paper presents the following templates for establishing an entrepreneurial engineering capstone design course for bioengineering students:

1. Instructor and student composition for strong multidisciplinary entrepreneurial engineering project development
2. Project selection and team formation processes for strong projects and teams
3. Timeline for instruction and major project deliverables
4. Use of assessments to facilitate student learning and project development

need

Engineering degree programs are challenged to develop students' capabilities that add value to their employers and to society at large. Among the highly desired capabilities are abilities to innovate new technologies. Entrepreneurial competency is especially important for bioengineers as over half of the roughly 700 manufacturers of biomedical instruments in the U.S. employ fewer than 20 employees and the introduction of new instruments is a main factor in being competitive [1].

The competitive landscape that bioengineering graduates will be facing is global and cross-cultural. Oftentimes, bioengineers collaborate with people from different cultures and perspectives, so an added benefit awaits those who are comfortable working within the context of diverse, interdisciplinary small groups. Bioengineering, being by nature the most interdisciplinary of the engineering fields, challenges practitioners to work in concert with individuals of diverse skills, working cultures, and points of view.

The need for broadened competencies for engineers is documented by prestigious national and international bodies. ABET Engineering Criterion 3 defines required abilities beyond those technical. Among these are outcomes (3d) multidisciplinary teamwork, (3i) lifelong learning, and (3f) professional and ethical responsibility. Graduate attributes and competencies defined by the International Engineering Alliance include social responsibility, ethics, communication, teamwork, project management, finance, and lifelong learning [2]. Attributes of the National Academy of Engineering's engineer of 2010 include: practical ingenuity, creativity, communication, business management, leadership and public service, ethics and professionalism, agility, and lifelong learning [3]. Among these are clear indications that engineers need abilities to innovate, lead change, and create ingenious technological products—be entrepreneurial!

our response to the need

This paper describes a capstone entrepreneurial engineering course that has emerged over nearly a decade of cross-college collaborations. In this course, students taste the entrepreneurial nature of product and business development that occur in the context of interdisciplinary teams preparing for business-oriented competitions. This paper presents the current state of a two-semester course required for bioengineering majors, entrepreneurship majors, and a diverse cohort of senior level students.

course goals and outcomes

The goal of the senior capstone course is to prepare graduates for innovative product and business development in a semi-authentic professional community of practice. Multidisciplinary teams work together to create a technological product and business plan, while also developing as professionals capable of interdisciplinary collaborative performances. The learning outcomes for the class address technical, business, and professional achievements:

1. Dispositions toward increased **confidence and mindset** to recognize evaluate and move toward opportunities.
2. Abilities to apply and defend **business development processes** to create a business concept for an envisioned solution that offers potential for a sustainable business investment.
3. Abilities to prepare and critically **read financial documents**, including a balance sheet, income statement, cash flow analysis and break even analysis.
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pedagogical approach

Instructional design for this course differs from traditional courses due to the professional and entrepreneurial nature of the course and its intended outcomes. For learning and assessment to be transferable to professional practice, the culture of the classroom must emulate the community of practice [4-7]. The instructional approach that has guided the evolution of the course has been based on the following principles:

- *Business Environment.* Assignments and assessments should be grounded in and resemble business practice.
- *Assignment Timing.* Assessments and student reflection exercises should be coordinated with the completion of a major challenge.
- *Cycle Iteration.* Multiple cycles of both the business model and technical solution generation are necessary.
- *External Reviews.* External input and review of the projects is sought at every stage of the process.

Each of these principles is discussed in paragraphs that follow.

Business Environment. Assignments and assessments should be grounded in and resemble business practice. Our experience with students in capstone courses indicates that undergraduate students are naïve regarding the importance of process control in the development of a solution. As a result, they resist requirements such as evidence of document controls and self and group assessment unless these assignments are visibly important to their success in events important to them in the future (e.g., business plan competitions, project funding proposals). This aligns well with motivation theories such as expectancy value theory [8, 9]. Linking these assignments closely to actual business practice and communicating this to the students is essential for motivation and intended learning benefit. An example is the IDEALS Team Contract assignment [10], which is closely modeled after corporate bylaws. Student teams prepare a set of bylaws (or a team contract) that defines the operating procedures and expectations for members and the team as a whole. The accompanying IDEALS learning module, used as a precursor to the Team Contract assignment, reinforces this relationship to the students.

Assignment Timing. Assessments and student reflection exercises should be coordinated with the completion of a major challenge. Timing of assessments both for formative feedback and for summative evaluation are important to maximize the effectiveness of learning. The scheduling of the major deliverables or challenges with their corresponding formative and summative assessments is carefully planned so they are part of the natural flow of the project and are aligned with common business practice.

Cycle Iteration. Multiple cycles of both the business model and technical solution generation are necessary to produce quality deliverables. Novices rarely anticipate that their first attempts at a solution will fail in some important aspect for both the business and technical aspects of the project. In order to give our students the opportunity to iterate, a proof of concept prototype and business model are delivered at the end of the first semester and documented in a Small Business Innovative Research (SBIR) grant proposal. A second more advanced prototype and full business

plan is delivered at the end of the second semester.

External Reviews. External input and review of projects is sought at every stage of the process. External expert involvement in the student projects reinforces to the students current practice in their chosen field and energizes the groups. These interactions also provide networking opportunities for both the students and the program. Constructive criticism and ideas for the continual improvement of the program are also benefits of nurturing external involvement of professionals.

four challenges

Teaching an entrepreneurial engineering projects course with students from several majors poses several significant challenges. These challenges threaten the success of the course with negative student attitudes, unsuccessful project completion, and poor documentation of true achievements from the course. Four significant challenges are addressed below.

Challenge 1: Instructor and Student Background.

Challenge 2: Project and Team Selection

Challenge 3: Course Timeline

Challenge 4: Assessment

instructional team

Authentic interdisciplinary learning requires an interdisciplinary instructional team. The current instructional team includes an instructor from the business school with a background in industry and small business administration, and two instructors from bioengineering one with experience in running a technical startup company and the other with a strong background in curriculum design and assessment. A teaching assistant is also a part of the instructional team. The current teaching assistant, a former student of the class, is realizing the results of his Ph.D. research in a new business venture.

Essential elements of the instructional team are a complementary set of experiences and expertise, and a strong commitment to realize the benefits of project based learning for their students. It is helpful to frame the class environment such that the classroom is seen as a research and development firm with the instructors as managers. Instructors then embrace the role of facilitator-manager with the responsibility to model best management practices for the teams they oversee. A single instructor can effectively manage three to five teams of three to six students per team. Expert business and technical mentors from outside the university are sought for each project, providing in-depth knowledge and resources for the project. The team's ability to engage these mentors effectively is a strong predictor of their level of success.

Challenges that come with an interdisciplinary instructional team in a university with a classic departmental structure are the administrative accounting for the shared responsibility. This requires administrative support at a higher than department level to be sustainable.

students

The makeup of the majors represented by the students in the course varies from year to year. Students enrolling in the course come from four cohorts: (1) bioengineering seniors for which the

course is their senior design course, (2) a mix of engineering, business, and science seniors participating in a corporate-sponsored scholarship program, (3) a group of engineering and business seniors that are part of an internship – entrepreneurship program which started the previous summer, and 4) business and engineering students recruited into the course by other students. The typical mix of students has historically been between a quarter and a third of the class are bioengineering students, a quarter to a third of the students are other engineering students, a third to a half of the students are from the business school and a small contingent of science students or math students fill out the roster. An agreement is in place with the other engineering departments for the course to count as a capstone class for their seniors in lieu of their more traditional course.

The response to budgetary constraints has changed the historical mix of departments represented. Currently there are 50 students in the class representing the following majors: Bioengineering (n=8), Electrical Engineering (n=3), Mechanical Engineering (n=1), Computer Engineering (n=2), Chemical Engineering (n=5), Civil Engineering (n=4), Computer Engineering (n=4), Physics (n=1), Mathematics (n=1), Finance (n=2), Management and Operations (n=2), Management Information Systems (n=1), Marketing (n=1), Communications (n=1), and Entrepreneurial Studies (n=14).

With this eclectic mix of university departments represented in the class, scheduling class meeting time is a challenge. The first semester is the most crucial period to have a common meeting time for all team members. In general, students are required to sign up for class time which meets twice a week for two hours. The second semester's content is focused more on execution of group goals and schedule conflicts require more flexible arrangements. Regular meetings by arrangement with supervisory instructors and their respective groups takes on a more important role.

project generation

Finding interesting projects that fit within the constraints of a two-semester course is a challenge. Our expectancy is that few of the projects that teams will work on will be market ready in the 32 weeks of the two semesters. It is required that the student teams add enough value to the project so that the project moves to a less risky phase of development and so offers an entrance or exit point for investment capital. One of the distinguishing elements of our approach is that scoping the project is the project group's responsibility. This requires them to take responsibility for project scope and to be strategic about what they plan to accomplish—vital skills needed in graduates.

number of projects

Our strategy is to start the year with roughly twice as many project ideas as there will be student groups. We then use a mini feasibility exercise to select the best projects for further development. For example, in fall 2010, the class began with 24 projects that were assigned to 24 pairs (one business, one technical person per pair). The preliminary feasibility analyses informed project screening to arrive at 11 projects. By the beginning of the second semester, ten projects remained.

sources of projects

Projects have come from university research both directly from our tech transfer office and

through personal contact with colleagues. Alumni networks are essential for both mentors and project ideas and sponsors. Some of our best projects have come from the students themselves. The mix of ten projects for the current year includes four sponsored projects, two university technology transfer projects, two international sustainability projects and two student generated projects. Students are contacted prior to the start of the first semester and are asked to bring their ideas to the first class. About a dozen of these students will be participating in a summer entrepreneurial engineering internship, from which they are to identify potential projects. Candidate projects are screened by the students and faculty, and those that generate the most commitment from the students are seeded into the mini feasibility exercise.

support of projects

Student groups are given an initial budget of \$500 per semester for prototype work. Projects that need further support may receive it with adequate documented need. Sponsored projects are funded at a minimum of \$5,000. Student projects are encouraged to generate intellectual property and form business entities. The intellectual property and investment that they generate is owned by the entity they create. The groups are required to participate in business plan competitions that have significant cash prizes for the winners. The winnings from the cash prizes are distributed according to the group's team contract that they are required to generate at the time the groups are formed.

project attrition

Projects may be terminated for a number of reasons including dysfunctional team dynamics and lack of either technical or business feasibility. It is important to have a strategy in place to anticipate and smoothly transition the team to either a new project or to assign the members and any project assets to projects they can strengthen. This current year required two project terminations. One team was handled by reassigning the members to the groups which they could strengthen, and one group moved to a new project at the start of the second term.

team formation

Team Makeup. A team size between three and six is workable. A team size of four is about ideal in terms of providing enough diversity of personalities, skills and working culture, while balancing the need to have every student actively involved. With groups sizes of six and above, the tendency is for some students to hide and let the more dominant students carry the team. A team size of three is the minimum to enable team dynamics for a strong team and to provide an environment that meets our learning objectives.

Time Constraints. The major time constraint that drives the first semester planning is having the teams produce a proof of concept prototype by the end of the semester. In order to meet this time constraint, teams must be formed by the end of the third week of the semester. The major time constraint for the second semester is a university-wide business plan competition in mid April. This requires completion of prototype, product and market testing by the middle of the term. The final portion of the term focuses on preparation of materials for technical and business presentations.

Student Selection. A number of strategies have been tried for team and project selection. These include: (1) students self-selecting after mixer activities and instruction on teaming strategies, (2) team member appointments based on criteria such as background, personality profiles and grade

point average, and (3) variations in between. Weaknesses of student-selected teams include less member diversity, teams built on previous social relations, and less realistic challenges in team formation and management. When teams are appointed entirely by instructor choices, lack of student volition transfers responsibility of inevitable problems to the instructors, and the instructor workload of matching students based on data is non trivial.

Our current practice seeks to strike a workable balance between respecting and facilitating student volition, ensuring strong student leadership and creating an adequate mix of personality, working cultures, and competency. Our process begins with a mini feasibility project that is assigned the first week of class. Students are randomly assigned in pairs to a project from our project pool which contains roughly twice the number of projects that will be pursued for the rest of the semester. The students are exposed to a rapid feasibility analysis process and then are required to do the analysis and generate a report in two weeks. The results from their analysis are presented to the class at the end of the two weeks. Concurrently the students are assigned to enter personal data into the CATME Team-Maker online software (Available at: <https://www.catme.org/login/request>). This software was utilized to generate potential teams. After listening to the mini feasibility reports from their peers, the students completed a project preference form which was used to display their interest. The inputs from Team-Maker and student interest were then used to create teams which the instructors felt had the best potential.

The final team creation step was to allocate one class period for students to negotiate changes. Students could initiate a change of project group by conferencing with the instructors and gaining approval from the respective teams. Although the process appears at face value to be involved, it was in practice straight forward and struck a good balance between student choice and adequate team diversity.

timeline for instruction - semester 1

The first semester focused on developing functional teams and delivering justifiable concepts for a design solution and business model. The semester contained a number of challenges that spurred learning and progress toward key deliverable for the term.

major deliverables - semester 1

Figure 1 illustrates the timeline for the major deliverables for the first semester and the timing of (IDEALS) formative and summative assessments. A brief description of each assignment is given below. The actual assignment documents and grading rubrics are available through the principal author.

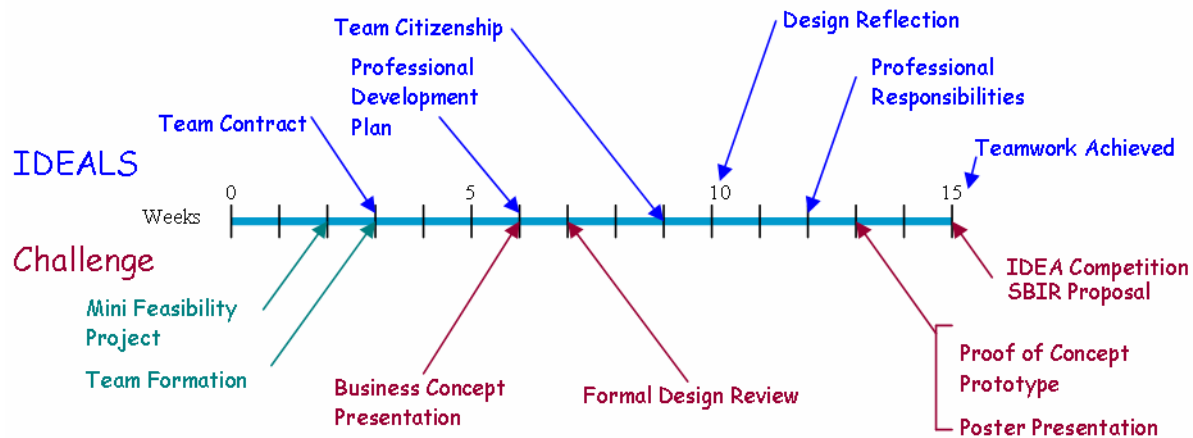


Figure 1: First Semester Timeline

Business Concept Presentation. The business concept presentation assignment requires the project group to perform an industry analysis, sales potential analysis, guru interview, and prepare a customer questionnaire. They must summarize their findings and present results in both a written report and an oral presentation to the class.

Design Review. The design review focuses on student's abilities to scope their project and establish a set of criteria for their design solution. This is the first design review which is presented orally and as a written report. It has the following sections:

- Performance specifications for the final product or service to be delivered (long-term)
- Performance specifications for the proof of concept product or service envisioned for the end of the first semester
- Summary of concepts considered to meet the proof of concept specifications
- Justification for selected concept
- Gantt chart for the semester
- Preliminary budget

Proof-of-Concept Prototype. The proof-of-concept prototype is vital to crystallizing the envisioned solution and its value proposition (value it provides investors) in the minds of the student team. Completed proof-of-concept prototypes and business concepts were presented in two venues. The business concept was presented as a two-minute video and one-page value proposition for a university wide concept competition. The technical solution concept, proof-of-concept prototype, and value proposition were presented at an engineering college poster and prototype presentation. This gave teams the opportunity to pitch their solutions and demonstrate the prototypes to a wide audience and to receive probing questions that might guide their solution development.

SBIR Proposal. Each group prepared a SBIR (Small Business Innovation Research) proposal as a summarizing document of their technical and business feasibility efforts for the first semester. Each team focused their proposal on an agency (NSF, DOD, etc.) that fit their project and prepared a proposal in the format required by that agency. This innovative component of our program is an excellent way to prepare students to write effective proposals and to learn to

communicate with impact. It causes them to reflectively consider the feasibility of their project. It also has the potential to provide funding for their business entity at the end of the course.

Concept Competition. The teams are required to enter a “business concept” competition at the end of the first semester. The format of the competition calls for the preparation of a one-page business plan and a two- minute video that communicates the value proposition of their project idea. The diverse requirements of this competition draw upon the varied interests and abilities of team members and help build credibility for team members who may not have been appreciated for their unique strengths. Teams also have fun creating humorous ways to show value from their product ideas.

assessments - semester 1

An important part of the learning and continuous improvement processes of the course is the strategic use of formative and summative assessments that align with project challenges. The Integrated Design Engineering Assessment and Learning System (IDEALS) resources facilitate learning and measure achievement in team project environments such as occur in this class [10]. These resources are accessed through the TIDEE IDEALS website: <http://ideals.tidee.org>. The IDEALS assessments that are utilized in the first semester are shown in Figure 1, where the timing of their use is shown in relation to the major deliverables. IDEALS assessments used in the first semester are described briefly below.

Team Contract. The *Team Contract* is a formative assessment given at the time of team formation. Teams are asked to identify important elements of effective teamwork and to create an organizational plan (team contract, or bylaws) that shows their consensus understandings and commitments. Instructional aids available to support the exercise guide teams through discussions of their understandings and development of a team contract. A template contract is available for teams to modify. The teams are prompted to anticipate possible problems and proactively develop processes to avoid or solve them.

The *Team Contract* is revisited later if and when team problems arise. A *Teamwork In-Progress* formative exercise is also available to assist in the process of revisiting the contract and helping teams to modify and work through conflict.

Team Citizenship. The *Team Member Citizenship* formative assessment is used about midway through the semester. This assessment focuses on individual member contributions to the team. The exercise asks team members to provide anonymous peer coaching to teammates, which is then combined with instructor feedback by the IDEALS system and sent anonymously to members to whom feedback is directed. The assessment also provides a snapshot of perceived effort of each individual’s performance. Instructor feedback is directed at the quality of the peer coaching that an individual provides, which incentivizes students to give serious attention to coaching that can make a difference.

Design Reflection. The *Design Reflection* formative assessment is used to facilitate student reflection on the design processes employed to-date and their impacts on project success. The assignment is given immediately after the design review challenge has been completed. Having recently received feedback on their design progress, the assessment provides students the

opportunity to identify changes needed in their design processes, and it gives instructors a snapshot of students' current metacognition around design.

Professional Responsibility. The *Professional Responsibility* assessment causes students to consider their project in the context of professional and societal norms. This formative assessment points students to professional norms, regulatory requirements, and global awareness and asks them to identify those most relevant to their project. They also identify actions needed to better comply with important norms. This assignment could be given earlier in the semester, but around the 12th week was the best time to fit it into a crowded schedule.

Teamwork Achieved. The *Teamwork Achieved* assessment is a summative assessment used for evaluative purposes. It is similar to *Team Citizenship* in that it asks students to rate their teammates, but it also probes actual contributions of each member, their understanding of teamwork, and transferability of teamwork learning to new situations. Students' evaluations of teammates are not shared with teammates being evaluated.

major deliverables - semester 2

The second semester focuses on the development of high performance teams and the delivery of a tested prototype and full business plan for its commercialization. The major deliverable and interwoven IDEALS assignments are shown in Figure 2 distributed along the semester timeline. Each major assignment is described below.

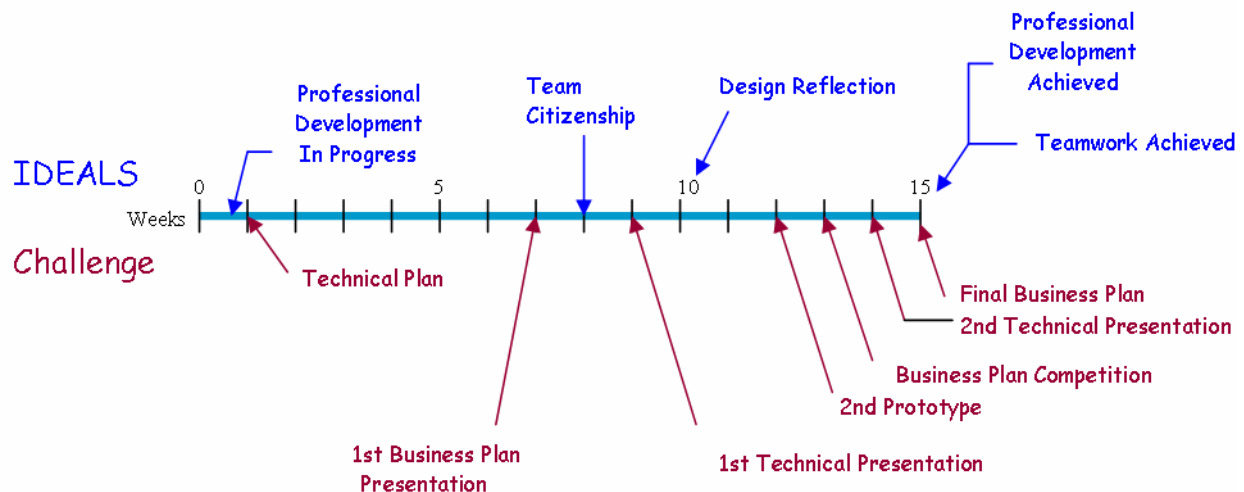


Figure 2: Timeline for Semester 2

Technical Plan. The technical plan defines the student's plan for completing their technical solution as required. This assignment requires the teams to look at the schedule for the second semester and draw up a plan to meet the stated course challenges as well as any that are project specific. The deliverable is a Gantt chart with responsibilities assigned to individual team members.

Business Plan Draft. Students need feedback on their business claims, plans, and communication if they will produce credible business plans by the end of the term. The team's first draft of a full business plan is due about week 7; it is also presented orally. An important function of this assignment is for students to articulate to themselves and teammates specific understandings and plans for their envisioned businesses. The teams also receive valuable early feedback from which to make improvements.

First Technical Presentation. The first technical presentation provides an early review of teams' technical progress and their abilities to communicate this information. Their presentations provide a progress check on the 2nd prototype and an opportunity to practice presenting to a technical audience.

Second Prototype. The 2nd prototype is documented in a technical written report and defended to the class and instructors. This presentation precedes the business plan competition, so it solidifies the technical features and shows performance data that can be a basis for value communicated in the business plan.

Business Plan Competition. The business plan competition is a formal written plan and an oral presentation judged by a panel of investors and entrepreneurs. Teams submit professionally bound copies of the business plan prior to the competition. The competition presentations occur in two stages, with winners of leagues in stage 1 competing for cash prizes totaling \$100,000 in the finalist round the next day. Judges include proven venture capitalists, banking professionals and technical experts.

Final Technical Presentation. A presentation before invited technical experts concludes the group's presentations. The final written documents are delivered at this time. Feedback from the judges of the business plan competition frequently results in edits that show up in the final business plan.

assessments - semester 2

The second semester utilizes a number of IDEALS assessments to continue prompting student improvements and to document changes in performance over the duration of the projects. Each assessment is described briefly below.

Teamwork In-Progress. The *Teamwork In-Progress* assessment focuses the teams' attentions on their team-level processes and their impact on team performance. Teams are instructed to discuss strengths and areas of concern related to team performance, then review and modify their Team Contract to address these issues. This review facilitates change in ways the teams operate so that they reach higher levels of performance.

Professional Development In-Progress. This formative assessment requires the students to compare their progress against the plan that was submitted in the first semester and to make adjustments as necessary. It provides the instructors a snapshot of their metacognition around their goals and aspirations. It also documents progress achieved after one semester.

Team Citizenship. The *Team Member Citizenship* assessment is used to provide individual feedback on member contributions to the team. Because members may become lax or new members join a team, this is vital to keep communication flowing to support high team performance. This formative assessment was described previously and is given about mid-semester to give students an opportunity to provide peer review of their teammates.

Design Reflection. The *Design Reflection* assessment prompts individual student reflection on the team's design processes, for the purpose of making refinements to their design processes. This formative assessment was described above and is given again right after the first technical presentation challenge.

Professional Development Achieved. The *Professional Development Achieved* assessment attempts to document individual student achievements in self-directed learning for the term. In accord with ABET requirements for lifelong learning, students must document how they recognized a need, developed a plan, and documented achievement in independent learning in the context of a professional design project experience. This is a summative assessment for their professional development.

Teamwork Achieved. The *Teamwork Achieved* assessment is a summative assessment described earlier. This assessment is used to document students' understanding of teamwork, evidence of team performance, and transferability of teamwork learning to future settings. This provides rich data for the instructor to evaluate the performance of the teams and of individuals on the teams. Often teamwork issues that surface with the flurry around the end of the course are captured in this assessment.

use of assessments

IDEALS assessments are an important part of this bioengineering capstone course. They provide formative feedback that aids the instructor and students to make informed changes and improve performance. They also provide evaluation data for grading and for program assessment. These issues are discussed below.

assessments for student evaluation

IDEALS Instructional Model. The theoretical basis for IDEALS instructional materials and assessments is summarized in the IDEALS instructional model [10]. The IDEALS instructional model is comprised of six steps: "Initiate, Define, Execute, Assess, Learn, Show". These integrate both instruction and assessment in the context of challenges that occur in the instructional setting. For us, the team project context offers key challenges that naturally lead to needs for the IDEALS materials.

The IDEALS instructional model is a two stage model. When a challenge is encountered the project group "Initiates" a response. Then in the "Define" aspect of the response, important needs are defined, goals are set and a plan is made. The final part of the first stage is to "Execute" the plan. So the first stage encompasses the encountering of a challenge and the solution formation and execution.

The second stage encompasses the “Assess, Learn and Show” parts of the model and addresses the metacognition that occurs in response to the challenge and aims to “elevate the learning to that of the reflective practitioner” [10]. The use of IDEALS assessments in key steps facilitates the reflection required to achieve these targeted levels of learning.

time load (student)/instructor

Whenever assessments are employed, there are legitimate concerns about the time required. Because the IDEALS assessments are imbedded into the natural flow of the projects, this becomes a natural way to both augment learning and obtain assessment data. On average a student will spend about a half an hour per online IDEALS assessment. Some assessments are entered individually and some are entered as a team after a preparatory team exercise. Peer-to-peer feedback is immediately available to the students when the evaluator releases feedback to them.

Instructors typically spend around 15 minutes per assessment unit. An assessment that is submitted on an individual basis for 50 students would require about 12.5 instructor hours to provide quality feedback. With experience, libraries of feedback responses can be built that allow the instructors to cut and paste based on common issues. This future enhancement should cut the instructor workload in half.

types of information provided

The use of IDEALS assessments in this bioengineering capstone course provides a rich set of information about student attitudes, perceptions of one’s own and teammates’ contributions, reflective thinking occurring in teams, challenges faced, and individual and team responses to challenges. A recent study of team reflection surrounding teamwork reveals that the IDEALS (formerly TIDEE) assessments prompt greater reflection and adjustments to improve performance [11]. The web-based data repository also supports longitudinal changes in students’ thinking and performances. The amount of information available to the instructor for grading and course adjustment is very large for the effort expended.

conclusion

This bioengineering capstone design course sequence has emerged from a decade of cross-college collaboration and refinement. Results are evidenced by greater entrepreneurial competencies of students, more business-ready technological products, and more substantive relationships with collaborators. Increasingly, the course has been managed to emulate business practice and operate on a rapid development cycle. The following templates for establishing an entrepreneurial engineering capstone design course for bioengineering students were presented:

- Instructor and student composition for strong multidisciplinary entrepreneurial engineering project development
- Project selection and team formation processes for strong projects and teams
- Timeline for instruction and major project deliverables
- Use of assessments to facilitate student learning and project development

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