Cross-Disciplinary Collaboration and Innovation for Engineering and Business Student Teams

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Abstract

A team was formed from students across campus including majors from business entrepreneurship, management, marketing, and electrical, civil, mechanical, and mechatronic engineering to compete in the U.S. Department of Energy Collegiate Wind Competition 2016. Requirements of the competition are to deliver a market-driven technology application, create an innovative business plan, and develop a deployment strategy. Two faculty advisers, a mechanical engineering assistant professor from the college of engineering and an entrepreneurship assistant professor from the college of business designed and delivered content to help student members effectively collaborate and innovate across their disciplines and form a cohesive and high functioning team. In addition to being members of the cross-disciplinary team, half the students were concurrently enrolled in a business management course with an emphasis in social entrepreneurship and market analysis while another half were enrolled in a senior capstone engineering course. Activities in the form of workshops were delivered to the team during weekly meetings to develop and enhance skills in team development, communications, project management, business development, brainstorming, and ideation. In addition, engineering students collaborated with business students during the business management course to provide technical expertise during market research and analysis and students presented to one another on topics related to their particular disciplines. This paper describes the workshops that were delivered, student reflections and feedback, and lessons learned throughout the experience based on faculty observations and student performance.

Introduction

Many engineering programs today include opportunities to work in multi-disciplinary teams.[1,2,3,4] This has largely been driven by industry's needs and requirements to become more multi-disciplinary and remain competitive in the workforce. This is also seen in the accreditation requirements of ABET where student outcomes are implicitly and/or explicitly collaborative in nature, e.g. general criterion 3: student outcomes (c) "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability," (d) "an ability to function on multidisciplinary teams," and (g) "an ability to communicate effectively."[5] Providing opportunities for students to work in cross-disciplinary teams is a desired academic engineering program attribute.

Because this project was primarily student-led and multi-disciplinary, various student-centered approaches were investigated as models to apply or adapt. Schaffer, et al.[6] investigated improvements in self-efficacy after students worked on cross-disciplinary service learning team projects. Students self-reported their confidence level on a number of individual and team behaviors and abilities. Average team size was 3.5 individuals from predominately engineering disciplines, however about 30% of the over three-hundred person class roster were from non-engineering majors. Results showed overall an improvement in self-efficacy based on a pre- and post-questionnaires however there was considerable variation within individual responses and

30% of respondents self-identified no change or a negative change in self-efficacy after engaging with the cross-disciplinary team. It is suggested that because of the cross-disciplinary nature of the project, students came into the group with limited experience with both cross-disciplinary teams as well as service learning design projects, which lead to unrealistic expectations of the type and amount of work required to effectively engage and deliver on the project. Avoiding unrealistic expectations and overconfidence was considered in the workshop design.

Fruchter and Emery[7] view cross-disciplinary teams as an opportunity to enhance learning by developing the individual through better understand of one's own discipline while also developing a deeper understanding of the disciplines of others. The interactions required to effectively work on a cross-disciplinary team forces individuals to describe, explain, defend, and understand their own areas of expertise in ways that surpass traditional learning environments. From questionnaires and surveys based on a four tiered model of increasing awareness from being aware of only one's own "island of knowledge" to understanding another's knowledge or subject, they find that enhanced cognitive development can be improved through cross-disciplinary project teams even when interactions occur remotely. Opportunities were created for students to engage in activities that required discussing and sharing one's discipline specific knowledge with others.

In a four year study of a general education course composed of students from across campus Machemer and Crawford[8] found that the over-riding factor influencing students' perceived value of the three teaching techniques, lecture, cooperative, and active-learning, was how relevant the technique was in supporting exam performance. Additionally, active and lecture-based teaching techniques were perceived by students to be almost equal in value, whereas cooperative learning was rated less valuable. Some of this difference is likely attributed to the fact that the four year study focused on a large, traditionally lecture-based course where some expectations and desires were to remain anonymous and discrete whereas cooperative learning techniques require individuals to work together, assume roles, and report out on the process as well as the particular content area. The cooperative learning structure does not allow for anonymity of the student participant. Because of the possibility that students view cooperative learning as a less valuable learning activity, the workshops were designed to coincide with CWC deliverables in order to create urgency and value for the workshop's content.

There are many engineering programs that focus on multi-disciplinary engineering projects and many that include industry sponsors[9]. These academic programs provide students with valuable project based-learning experiences with opportunities to interface with industry in a safe environment focused on learning and development. However, most of these programs are fundamentally engineering projects requiring solely engineering solutions. Additionally, while a solution may not exist, *a priori*, project sponsors generally provide adequate constraints and feedback to help guide the engineering student toward a viable solution. The CWC has no such sponsor and the problem definition is entirely student defined.

The Department of Energy Collegiate Wind Competition 2016 (CWC) brings together many different disciplines to compete on a national level. Teams are responsible for identifying a market need and conceiving of a device that solves the need and uses energy derived from wind as its sole source of power. Additionally, the competition requires teams to identify issues

involved in deploying the unique application within its target area. Students are to design and build a prototype wind machine, develop a complete business plan that supports the application, and strategize how the wind turbine is to be deployed. These deliverables are judged during a three-day competition where the technical team's prototype is tested in an on-sight wind tunnel, the business team presents the business plan to a panel of industry representatives, and the deployment pitch is presented in front of a national audience of experts. These three challenges are highly cross-disciplinary in nature as well as very open ended. Not only do students need to conceive of a product, it must be based on market research and as a result there are no predetermined technical requirements or specifications. There is no predefined problem that needs a solution. Students develop their own criteria for what makes a viable product, market, and customer. These challenges require students to be entrepreneurs and work collaboratively and openly in an environment that demands careful, consistent, and precise communication between students with diverse backgrounds and experiences.

Team Organization

The core team was formed from students enrolled in either social entrepreneurship or engineering capstone. The guiding tenants of social entrepreneurship are to "(1) aim either exclusively or in some prominent way to create social value of some kind, and pursue that goal through some combination of (2) recognizing and exploiting opportunities to create this value, (3) employing innovation, (4) tolerating risk and (5) declining to accept limitations in available resources."[10] In this course, students explore what distinguishes social innovations and how to apply business start-up knowledge, skills, and abilities in order to accomplish them.

The mechanical and mechatronic engineering capstone course is two semesters-long. Students learn many aspects of project and product development, project management, budgeting, designing and defining engineering specifications, testing, and customer/client relations. A team of five engineering students were assigned to the CWC plus two other engineering students volunteered.

The senior capstone course outcomes aligned well with the CWC schedule. In the first term, students work with a customer to identify the engineering specifications and design validation test procedures. Throughout the semester capstone teams give three formal project presentations to peers, clients, and faculty. Presentations include a project design proposal, preliminary design review, and final design review. The final design presentation includes a completed budget, bill of material, CAD models, wiring schematics, and custom fabrication needs, among other requirements. The second term focuses primarily on fabrication, testing, and design validation with the required hardware deliverable showcased during the end of the term.

Workshops

A just-in-time approach was adopted for delivering content to students in the form of workshops focused on the immediate needs of the team. This model was selected to more closely represent the dynamic environment of a new business technology startup and to avoid creating an environment where assignments were given and deadlines were established and driven by the instructor. Workshops focused on the following areas: developing core team values, writing a team contract, understanding behaviors to improve team performance, self-assessing behaviors,

market analysis and product development, and sharing expertise. Workshops were presented throughout the fall 2015 semester during weekly team meetings. They were designed to include a brief explanation of a concept or theory, lasting between ten and twenty-minutes, followed by an activity in which students worked collaboratively. The collaborations were generally designed to get students to interact with one another as well as to provide them with skills and products that would be used as the framework for future deliverables and/or internal processes.

Core Team Values

One of the first learning opportunities was an activity designed around creating core team values. The students were briefed on the importance of creating core values as a team and how the overall values of the team result in the collective understanding of one's mission and a sense of belonging, which leads to a stronger commitment to the team. Individuals were then given a list of over fifty words that represented values such as ambition, kindness, integrity, etc. Students were then asked to pick five words from the list and/or supplement the list with their own words and rank the words in order of personal importance. All words were then combined into one list and ranked based on how many times the word was selected by an individual. All the words were reviewed and discussed. Some words were combined into one if the team felt that one word could adequately represent multiple words. This continued until the team had a list of five words that best represented the core values of the team. The goal of the activity was to encourage the collaborative, rather than individual, thinking that was found as a key finding in Fruchter and Emery's[7] study.

Team Contract

Once the team had a list of core values, they created a team contract. The team was provided with a template adapted from Trevisan, et al[2]. Elements of the team contract included roles and responsibilities, team relationships, team meetings, individual expectations, documentation and communication protocol, and conflict resolution. The contract was completed and circulated among all members and once approved, it was signed and became the governing document for the team.

Supportive Behaviors and Self-Assessment

Presentations on teamwork and how to contribute to a high achieving team were adapted from the instructors' experiences as well as Pellerin[11] and Trevisan, et al[2]. Key elements include describing and understanding the motivations for why individuals work on teams and what the underlying needs of the individual are in working on a team and how to nurture and support those needs to maintain a positive, constructive, and successful team environment. These characteristics were presented and discussed with the students and used as a self-assessment tool to evaluate each individual's contribution to the team and to identify areas that need to be addressed or supported for process improvement.

Market Analysis and Product Development

The market analysis workshop focused on case studies of products that were conceived of by well-known companies, taken through production and distributed to the customer and failed. In all cases, the failure was a lack of adequate market research and specifically not appropriately capturing the voice of the customer and/or misunderstanding the situation or way in which the product is used.

The new product development workshop focused on identifying the essential information necessary to assess a potential product idea. A concept disclosure template was provided that is commonly used in industry to evaluate product ideas. The template is a relatively simple document that includes placeholders for the following items related to the concept: picture/image, problem definition, how product solves the problem, description of the customer, description of the market, competition, competitive advantage, intellectual property or unique technology, and how the product is to make money. This is used routinely to make decisions at the executive/management level in a typical company. It was suggested that the students utilize the concept disclosure template to track all concepts being considered.

Sharing Expertise

It was clear at the onset that engineering and business students knew very little of the others area of expertise. As a result, several presentations were prepared by the students and for the students. Engineering students prepared and presented to the non-engineering students. Engineering students often do not realize what they know and often do not recognize that other people may not know or understand the concepts and terminology that they do. Engineering students prepared and presented a summary of the basics of energy, power, wind power and efficiency and reviewed key performance and design considerations for developing wind driven power system to the entire team.

Likewise, non-engineering students presented the fundamental of elements of a business plan, market research, and customer perspective. Groups of three to five business and engineering students presented to the rest of the team. Time was devoted to answering questions and addressing issues or concerns of any and all students.

Engineering students participated in several events held during the market research class. As teams of business students were conducting market research, reaching out to potential customers, and investigating market leads and contacts, engineering students came to the marketing class as technical experts and collaborated on the technical aspects of the market driven concepts. Approximately, two one-hour sessions were dedicated to having one engineering student per market research team collaborate, discuss, and identify technical issues that related to the market opportunities.

Assessment

The goals of the assessment were to provide information on how students self-identify with working in teams and to understand their level of experience. Additionally, it was hoped that by assessing pre- and post-semester, the effectiveness of the workshops could be determined. Two questionnaires were given to the students, one at the beginning of the semester and one at the

end. Both questionnaires included Likert-scale questions, yes/no responses, and space for comments. The pre-semester questionnaire focused mainly on teamwork experiences and attitudes and included the following questions.

1. Have you worked on an academic team?
2. Do you like working on a team?
3. If assigned to a team project, how would you feel?
4. Have you ever been trained to work on a team?
5. Is it necessary to work on a team?
6. Are you well prepared to work on a team?

The second questionnaire was administered at the end of the semester and included the following questions plus several open ended summative questions. The questions with Likert scale responses follow.

1. Have you worked on a team with students from a different college?
2. Considering the CWC experience, do you like working on a cross-disciplinary team?
3. If assigned to a team project, how would you feel?
4. Do you think you were well prepared at the beginning of the semester to work on a team?
5. Do you think you are now better prepared to work on a team?
6. Compared to projects with students in your major, what did you think of working with students from a different college?

The summative questions queried students for what they liked, what needs improving, and what recommendations they had for the stated improvement. These were used as a formative assessment of team progress and overall team efficacy.

Results

A total of ten responses were collected from the pre-semester questionnaire and seven for the post-semester. Frequencies of responses to each Likert scale option or frequency of yes/no responses are provided in Table 1.

Table 1. Pre-Semester Questionnaire Results

Question	**Likert Scale/Response and Frequency**				
1	Yes 10	No 0			
2	Dread it 0	Not Really 1	Neutral 5	Like to 3	Love to 1
3	Dread it 1	Not Really 0	Neutral 3	Like to 0	Excited 6
4	Yes 7	No 3			
5	Yes 10	No 0			
6	Not at all	Not Really	Neither	Probably	Absolutely

	0	0	0	3	7

Post-questionnaire frequency of responses are shown in Table 2.

Table 2. Post-semester Questionnaire Results

Question	**Likert Scale/Response and Frequency**				
1	Yes 1	No 6			
2	Not at All 1	Not Really 0	Neutral 1	Like to 4	Love to 1
3	Dread it 1	Not Really 0	Neutral 1	Like to 0	Excited 5
4	Hard 4	Same 2	Easy 1		
5	No 0	Probably Not 0	I Don't Know 2	Probably 2	Absolutely 3
6	Hard 4	Same 2	Easy 1		

A self-assessment was collected midway through the semester. Eight behaviors were assessed in which students were asked to respond to whether they exhibited the behaviors fully, usually, seldom, or never and provide a justification or reason for their rating. The eight behaviors included showing appreciation, addressing shared interests, including others, keeping all agreements, being optimistic, being outcome committed, avoiding blaming others, and understanding ones role and level of accountability (adapted from Pellerin[7]). Though the self-assessments were limited, highlights of these provided poignant insight into student experiences. Students recognized when they did not meet the behavioral standard and gave examples or details of their performance. For example, one student wrote, "I have been upset with our progress…, yet have done little to resolve the issue." Another student said, "I try to focus on the outcome but sometimes I get bogged down in the details." In addition to assessing ones behaviors, the questionnaire also asked students to describe which attributes of the team support good team work and what one thing the team could do to improve its performance. A summary of the answers are included in Table 3.

Table 3 Answers to two questions from the student self-assessment.

Which attributes of our team support good teamwork?	**What is one thing that our team could do to improve our performance?**
"willingness to ask questions and be persistent until an answer is found."	"tech team should approach business team more often asking if they need help"
"weekly meetings and open collaboration"	"less reliance on professors. I believe we have enough momentum that students can collaborate more independently and produce quality results." "It doesn't feel as a student led team anymore."
"weekly meetings"	"review the team contract"

Discussion

The team socialized well and seemed to enjoy one another's company. Meetings started on time, though often lasted longer than scheduled, were well attended, respectful and the students were engaged. Some support was given early in the semester on how to run an effective meeting, creating and managing agendas, and managing action items. These skills were taught to the student leads and emphasized throughout the semester.

During the workshops, students seemed to participate with enthusiasm and interest. During the team values workshop, students actively discussed various values and definitions and collaboratively developed their list of guiding principles. Likewise during the workshop on self-assessments and behavioral characteristics that add value to team collaborations, the students were engaged and interested. The business professor led a discussion on the importance of appropriate and adequate market research and asking the customer for input. This was a particularly rousing workshop in which the students participated and were highly engaged. The workshops seemed to provide adequate information for students to engage in collaborative activities such as market research, developing a team contract, and ideation. However, much of the follow up necessary for evaluating concepts and assessing ideas fell flat. The students did not seem to continue or build upon any momentum that was created from week to week.

It took at least two months for the team to take ownership over the project and commit to taking on and completing assignments. The team missed all internal deadlines, meetings lasted longer than planned and often without resolution on current issues, and there was a lot of confusion with roles and responsibilities. As noted in the self-assessment (See Table 3), some students wanted more autonomy however when given full control of the project, they missed most internal deadlines and deliverables and had difficulty defining goals and direction on a week-to-week basis. This seemed to indicate a disconnect between what the students understood of themselves and how they contributed to the team.

This is consistent with the limited results of the pre- and post-semester questionnaire. Six out of ten students from the pre-questionnaire and five out of seven students in the post-questionnaire answered that they would be excited about the opportunity to work on a team. This equates to about 65% of all students excited about working in a team environment, which seems consistent with a team of volunteers. However, 70% of students in the pre-questionnaire, i.e. at the start of the project, believed they were absolutely well prepared to work on a team, which dropped to only 28% at the end of the semester. Additionally, of the students that indicated that they were excited to work on a team in the pre-questionnaire, 100% felt that they were absolutely well prepared for teamwork. Whereas in the post-questionnaire, four out of seven respondents (57%) indicated that they thought it was hard or really hard to work on a team with students from a different college. These results seem to indicate that serval students started the project with high expectations of themselves and were perhaps overconfident about working in a multi-disciplinary team.

After careful consideration and reflection on the past semester, the issues and struggles that the students had do not seem to be based on a difficulty of working together or bringing together students from diverse backgrounds. The main challenge came from the nature of the competition and specifically the fact that the students had to conceive of an innovation or application that did

not exist, decide whether the idea had merit and design both a market analysis and business plan and prototype to justify the concept. Students were asked to be entrepreneurs.

When ideas were proposed to the team, students struggled to find viable solutions and seemed clearly frustrated and discouraged, to the point that during a couple meetings, students lost enthusiasm and confidence for wind power and mentioned how much easier the competition would be if they could design with solar power. The students were working hard to find a viable solution using wind power but the natural constraints of wind, including site specific wind resources, intermittent availability, land and wildlife issues, and overall system cost, limited options and narrowed students' view of the possibilities, adding frustration and at times degrading attitudes toward the project.

In some regard, these issues are faced by individuals and companies on a regular basis and exposure to the reality of starting a business and its inherent challenges is a valuable learning experience. Characteristics of successful entrepreneurs including resourcefulness, creativity, and willingness to accept ambiguity or tolerate risk[12] are the same characteristics that the students were being asked to develop in order to succeed as a team of the CWC. Some of these characteristics are necessary for success in college, however the ambiguity and creativity, if not managed well, can easily lead to disgruntled and disappointed behaviors and attitudes. Unfortunately, students were not well prepared to manage these complex issues.

Another area that seemed to be particularly challenging was the fact that little was known of the process of new product development. Neither group focused well on what was unknown about an issue and attempt to resolve the unknown issues in order to gain clarity. Instead, they would focus on one discrete data point or set and use that to drive discussions and decisions rather than look for the flaws or fault in the data and try to overcome these with more information. As a result, decisions were made based on only partial information. Students struggled to find something concrete on which to make a decision where the act of making a decision was more important than the quality of the data on which the decision was based. This speaks to how uncomfortable the students seemed to be with ambiguity and the unknown.

Lessons Learned

Based on the past semester's performance and quality of the deliverables there are four main areas to focus on for improving the overall performance of and experience for the students, these are (1) describe in-depth the new product development life-cycle from the perspective of production as well as business and provide examples of successful and unsuccessful product launches with performance metrics, (2) provide consistent and continual support to student leads on how to manage teams, (3) have guest lectures share their experiences of being an entrepreneur, (4) and focus on the overall team as the entity that drives decisions and deadlines as opposed to the supporting courses in which the students were enrolled.

One of the biggest challenges for the students was not knowing the overall process of starting a business from conceiving the idea through commercialization, launch and product roll-out. Because of their lack of understanding of the process they waited for others to inform them of what to do and when, rather than taking the initiative based on a clear understanding of the

process. They were reluctant to start the pursuit of an idea. It seemed that the risk of failure prevented them from starting. The reality of a small business startup is that most ideas are not good ideas, but it's the pursuit of ideas, even bad ones, that ultimately leads to an idea worth pursuing. Knowing that the process of new product development is fraught with failures might help students overcome their reluctance to start and tendency to look to others to make progress before they are willing to invest time and effort. Additionally, knowing the timing and process for new product development could help students understand that even though they might come from different backgrounds and have different expertise, no one individual is likely to know the "correct" idea to pursue.

Additional support will be provided to help inform and guide student leads and individual team members. Agendas and timelines will be reviewed weekly with appropriate meeting goals identified and support provided for how to reallocate resources should the need to adjust workload be needed. Additionally, student leads will be coached on how to divide tasks into small action items that can be more easily tracked and managed.

While the social entrepreneurship class had many guest lectures and opportunities to interface with business leaders and entrepreneurs in the local and regional community, these events were focused on understanding various market segments and were not intended to provide an overview of the business startup or product development process. Bringing in guest lectures that have entrepreneurial experience and that can describe the process of starting a business or developing a new product line would help the students better understand the overall process as well as help them to identify key elements and priorities related to market research and analysis during the concept development phase.

A major organizational change that will be implemented in the future will be to allow the CWC to form for and by students at the beginning to enable true student governance and leadership. The CWC proposal was awarded in the spring semester and since both faculty members that submitted the proposal were new to the University, they appointed several students based on recommendations from others and not based on firsthand knowledge. While these students were extremely helpful in getting the CWC off the ground, because they were selected by faculty they looked to the faculty for direction and decisions as opposed to taking the initiative themselves to make decisions. Additionally, when the CWC grew, it grew because of students being assigned to the project from either the social entrepreneurship or engineering capstone course, and again, the motivation of the assigned students was primarily based on their course responsibilities and not their or the team's organization and direction. In the future, CWC membership will be solicited across campus with the overall direction and decisions made by students for students with the faculty advisors providing support and guidance rather than driving the overall direction and decision making.

Finally, a change was made at the start of the spring semester. Each student committed to a contract in which they agreed to work at least 10 hours per week and volunteer for one or more administrative positions in exchange for the opportunity to travel to New Orleans, LA for the competition. The contract was created to make more explicit the expectations of being a member of the team. The hour requirement includes time spent on assignments for both business and

engineering courses related to the CWC. Students that were not able to commit to ten hours per week are still able to participate, however they will not necessarily go to New Orleans.

While there were many lessons learned and the conclusions are thus far based on faculty observations, insight, and limited student feedback, the overall experience for both faculty and student has been successful, enjoyable, and challenging. The Chico State CWC team submitted its final competition report to the Department of Energy which includes a comprehensive report of the business and deployment strategies and technical design solution. The team is now well poised to be competitive at the event in New Orleans at the end of May 2016.

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