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Engineering Leadership Development using an Interdisciplinary Competition-based Approach with Cross Functional Teams

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Abstract

This paper presents results of an effort to employ an experiential learning program, known as the EcoChallenge, using cross-functional teams to address a “real-world” sustainability issue to aid in the development of leadership skills of undergraduate engineering students. While experiential learning has been demonstrated to be an effective tool for leadership development, integration of disciplines outside of engineering at the undergraduate level, specifically business majors, in cross-functional teams has presented logistical, assessment, and educational challenges in a class setting. The lack of such integrated educational experiences may be problematic as an abundance of anecdotal evidence and calls by professional engineering organizations, including ASEE and NAE, suggest that engineers must learn to work effectively with accounting, marketing, communications, and other functional group members within a given organizational structure to attain project success. And while those calls are not new, there are only a handful of documented undergraduate-level capstone experiences focusing on leadership development that have crossed college boundaries in a graded academic course, and thus have a higher level of risk for the student versus extra- or co-curricular activities.

A survey of engineering alumni in senior management positions identified the ability to effectively work in cross-functional teams as one of the top three skills engineering students lack upon entering the workplace. Using that data and anecdotal evidence of need as drivers for curricular change, a competition was designed employing teams from both engineering and business schools to identify and solve a sustainability problem. Each student was not only focused on the overall competition, but also in defining their roles and leadership opportunities including influencing stakeholders or teammates in specific areas of action. Additionally, teams and individual students had periodic metrics to report and milestones to achieve. The project culminated in a formal business pitch from each team in a competition assessed by a panel of experts. Students were also provided opportunity to follow-up with their projects into the implementation phase.

This paper attempts to address the question of how can a sustainability-focused, semester-long, course-based learning experience that integrates students across academic colleges be used to help students develop leadership skills. The paper will include a review of the pedagogical approach and the structure of the capstone leadership development project for business and engineering majors in the context of a competitive sustainability challenge program using cross-functional teams. Collected assessment data of leadership development, analyses of the data, and recommendations are provided. Results of direct assessment show a statistically significant improvement in in three of four leadership areas, while student self-assessments do not show statistically significant improvement.

Introduction

This paper presents results, including end-of-class student surveys, mentor assessments of student development, and lessons learned from execution of a capstone leadership development experience for engineering students participating in a single-semester class with a formal grade. The platform for the experience was problem solving in cross-functional teams consisting of engineering students, business students, and scholars from a multidisciplinary program. All engineering students in the class were selected through an interview process and had previous leadership experience. However, the students from other disciplines involved in the capstone experience were not part of the engineering leadership development class. Therefore, while the information presented here may be useful to the general community of engineering leadership development, it may not directly apply to all curricular circumstances.

There is a body of literature regarding the need for engineering students to learn to work more effectively with other disciplines within a business structure to attain project success. Whether espoused through visionary calls [1] or compilation of industrial feedback [2], it is generally accepted that engineers need "soft" skill development to succeed in team environments in the "real world." A number of efforts have either documented the need for development of skills necessary to work in cross-functional team or methods to address development of such skills, but not specifically engaged in a cross-functional or multi-disciplinary teaming efforts. For the purposes of this paper, we refer to only six works [3-8] that substantially either reference the enormity of literature on why engineers need such skills or they present cited contributions to the understanding of the needs for engineering students to learn to work with other disciplines in business environments. While there are dozens of other relevant works, these works [3-8] were used, along with input of alumni, as the basis for the justification for the launch of this program.

Additionally, there are a number of published works describing methods of interfacing engineering students with business concepts, business student teams, or co-curricular activities [9-13]. Again, there are numerous other works besides these examples. However, the cited literature establishes that it is possible to help engineering students learn aspects of successful teamwork with students in other disciplines. Yet, the literature also points to a serious pain-point – the diverse nature of such teams may lead to rapid breakdown if effective leadership is not employed [14]. With cross-functional teams becoming more widespread and critical to success in addressing issues that cannot be solved within corporate silos [15], the realization of their challenges is also becoming more evident, with documented widespread dysfunction [16].

For the purpose of this work, a cross-functional team is defined *as a group with different functional (or discipline) expertise working with a high degree of interdependence toward a common goal for the purpose of addressing a challenge that crosses departmental boundaries*. This definition is an amalgamation of several published definitions [17-19], but one that has resonated with engineering alumni leaders that are stakeholders in the discussed leadership development program. A survey of these alumni noted the value of using cross-functional teams to stimulate innovation, to create consensus on direction, to enhance cross-unit communication and alignment of purpose, cut through barriers that inhibit product development, improve accountability for action, and develop leadership skills within an organization. Cross-functional teams are widely recognized as a valuable and strategic tool for bringing new ideas and products into the marketplace by cutting through obstacles that tend to inhibit innovation [15].

While it has been found that experience with cross-functional teams is necessary for students to grasp the need to develop skills that will allow such teams to succeed [20,21], the challenges to implementing a significant learning activity using a cross-functional team experience is non-trivial. Business and Engineering schools have different expected outcomes, accreditation, and assessment criteria. One successful example of integrating business and engineering students in an assessed (graded) class using cross-functional teams that is focused on delivering a tangible outcome is the EPICS program at Purdue (https://engineering.purdue.edu/EPICS) [22].

Yet, there are challenges to implement a similar model in an environment where curricular 'crossing of boundaries' is not embraced. The purpose of this paper is to report the lessons learned in exploring the question of how can a sustainability-focused, semester-long, course-based learning experience that integrates students across academic colleges be used to help students develop leadership skills.

Methodology

Using examples from the EPICS program, the structure of an existing capstone leadership project involving cross-functional team-based competitions was strategically modified in the second year of execution. The original program involving students in the College of Engineering and leadership students in the College of Business is documented elsewhere [23-25]. One of the key structural changes was tasking the engineering students to lead the cross-functional team through an even level of accountability for team performance through graded assessment of milestone performance. Such accountability was not always present for the non-engineering team members.

For the program itself, cross-functional teams engaged in a competition using a "real-world" framework with the potential reward being a tangible result visible on their campus or in their community. To that end, the entire framework was owned by the student teams. The teams were tasked with identifying and selecting a sustainability problem on campus or in the nearby community that they would address, resolve operational issues using skills developed in leadership training, with the final deliverable being a team presentation of their solution and the economic assessment in a business "pitch" format to a board of experts from the associated colleges, the university's Facilities Management group, and alumni mentors.

While the competition framework for the cross-functional team experience in the capstone leadership development course provided significant learning opportunities, it created challenges for assessment by the instructors and for execution of the projects. Assessing individual leadership development in any team environment is non-trivial, but even more challenging in a team of students with previous leadership development. Differentiating skills improved or developed as a result of the capstone experience was important.

Further, the requirement that the students identify and select a sustainability-related problem that could actually be addressed and accomplished by working with a viable stakeholder introduced ambiguities and collaborative difficulties. Not only did the teammates have to reach a consensus on the problem they would ultimately address, they had to quantify viability by working with external stakeholders to assess if resources would be available should the project move forward and quickly assess implementation dynamics within the organizational structure. Finally, the students had to determine return on investment necessitating that specific costs and revenues for the project components were quantified.

Four areas of leadership development were targeted through the capstone effort – ability to motivate, ability to communicate vision, ability to listen to all the stakeholders and incorporate key concerns into the project vision, and ability to empower their teammates (getting teammates into the right places and with the right resources to succeed.) These four areas were selected through consultation with alumni and faculty stakeholders in the collaborating development programs as the core challenges of leading cross-functional teams in an environment where the students would have to meaningfully engage university operations and staff that had no stake in the program. It is important to note that some (not all) of the staff of these university operations initially viewed the EcoChallenge program as interfering with their work and mission. Yet the students had secure information and resources from these staff to move their projects forward.

Finally, it should be noted that several assessments were performed during and following the project to track project progress and individual student learning (both by faculty and self-assessment) Project performance was assessed by achieving specific milestones. Self-assessment by the students was performed at the end of the project. Assessment of student leadership skills development was done by project mentors via qualitative perception of skill level and then converting the assessment to a number scale both early in the project and following completion of the project to provide a development differential.

Procedure

This section describes the details of execution for the capstone project from initiation to completion. Throughout the process, instruction was provided to assist the teams in meeting their deliverables. Faculty from the College of Business discussed pitch content and presentation delivery style. This was augmented by instruction from engineering faculty on energy analysis, cost-benefit ratio analysis, on return-on-investment (ROI) and triple bottom line analysis, as well as logistics. However, this instruction was supplemental and the main learning activity was performance of the project.

The capstone leadership project was actually launched at the end of the prior academic year after the participants were selected. The kickoff meeting included all three groups of students engaged in leadership development (engineering, business, and multidisciplinary scholars.) The framework of the competition was provided and previous participants shared their experiences.

A second kickoff was done after the start of the new academic year. At this launch, a detailed timeline was presented and the students were provided with specific milestones. While the team structure would be determined later, the general organization of the cross-functional teams was explained. Details of the competition, including problem identification were restated.

Identification of Sustainability Issues

The students were tasked with identifying a problem found on campus or in the local community. The selected project had to meet the following criteria:

- The problem must be related to a sustainability issue in food, water, or energy
- The problem must be solvable within reason. For example, no projects would be considered if funding was unlikely, special permissions that would take long-range

planning were required (such as a vote by the University Trustees,) or anything endangering health and safety.
- The problem selected had to require a cross-functional team effort for solution.
- The solution must meet the conditions of judging (positive ROI, proven stakeholder buy-in) before it can be "pitched" to a board of experts for further consideration.

Team Organization and Structure

Team composition was selected by distributing talent as evenly as possible with the requirement that two engineers be on every team. The program directors of the leadership development organizations used the known strengths and weaknesses of the students to assign team members in an iterative process. Conflicts in schedule and other factors were considered. However, final team composition was sometimes determined by *ad hoc* means when the main factors previously described were considered equal.

Identification of stakeholders

After ten days, the teams presented their potential sustainability problems in short (1-2 minute) discussions. This discussion had to include identification of stakeholders. While teams were connected to potential stakeholders by faculty mentors, the teams were tasked with identifying all key stakeholders needing to be engaged. This turned out to be a significant challenge, because many of the students felt this information should be completely provided to them. As will be discussed later, the lack of stakeholder engagement left some teams with incomplete project data, leading to the call for increased communication (especially listening) skills development.

"Pitch" Rubric

As with the competition in the previous year, the teams were presented with a rubric for the "pitches" that were to be the basis for selection of the winners of the competition. Scoring percentages and categories included 25% for "Validity and relevance of claimed benefits," 25% for "Implementation practicality and risk," 20% for "Rigor and believability of the ROI analysis," 15% for "Adequately addressing potential concerns of all stakeholders affected, getting "buy-in", and professionalism in dealing with experts," and 15% for "Clarity and completeness of presentation." Discussion of each component of the pitch were provided throughout the course of the project.

Executive Coaching

By week seven, the teams created videos of their draft pitches that were analyzed by the program directors and the competition sponsor. Teams were provided written critiques. In addition, each team participated in teleconferences with the competition sponsor, an alumnus who had been CEO of several companies, for the purpose of helping them improve their team dynamics and overall pitch quality. It is important to note that this alumnus also participated in earlier coaching directed by the faculty and local mentors.

Individual Leadership Development

The program was established to help engineering undergraduate students develop leadership capabilities in an experiential framework of a capstone effort. The engineering students were assessed and graded on numerous activities showing the progress of their project and in individual leadership reflections and essays. This placed an additional level of accountability for the engineering students not entirely matched by the business students and scholars from other programs. Students were assessed by the faculty and external mentors during the course of the program. Students also performed self-assessments of the development of their personal leadership qualities and the overall worth of the program.

While actual execution of the project was done in a cross-functional team, each engineering student was asked to identify how they were developing their leadership skills within their project. Specifically, they were asked to provide their personal narrative to

- Explain his/her vision of the project and why it was appropriate to undertake
- Describe what information he/she would be responsible for gathering and the communication strategy required
- Describe which task(s) you he/she would lead in implementing your project. Provide enough detail to explain how you will address additional stakeholders that you need to influence, obtain resources you need to acquire, and overcome potential barriers
- Present a timeline for implementation for your individual work (working with your teammates) broken down by tasks and expected times to implement
- Identify resource allocation to complete the plan

Student self-assessment included an initial effort to rate their leadership abilities. Following the pitch competition, students were asked to assess their satisfaction with the leadership development experience, the level of challenge (difficulty) of the project, and their understanding of leadership concepts put into practice.

Direct assessment of student leadership development was implemented in the most recent year of the program. Mentor and faculty assessment of leadership development consisted of uneven contact time (more for faculty, less for mentors.) However, both groups analyzed engineering student's personal work and interaction in the team environment throughout the program. Four areas were assessed early in the program and after the pitch competition: ability to motivate their team and meet milestones, ability to communicate their vision for the project and team, ability to listen to their teammates and act, and ability to empower their teammates by getting the team members into the right places and with the right resources to succeed.

The actual pitch competition was held as an all-day event, including an evening awards ceremony. Teams were given 25 minutes to pitch their solutions and financial analysis with a question and answer period included. Teams were provided written and oral critiques of their pitches, with emphasis on potential improvements. Post-assessments for personal and leadership development were also performed.

Results

Each year, six to nine projects were developed around local sustainability problems, including installing hand dryers to replace paper towel usage, replacing exterior building lights with high efficiency LEDs, implementing a recyclable and reusable "to-go" box at the dining halls, installation of motion sensing thermostats to control HVAC units in dormitories, process energy and efficiency improvements at a local microbrewery, implementing a "green roof" on a campus building, a new watering system for the campus arborist, replacement of lighting in the campus aquatic center, and a summer shutdown of a lightly used campus building. Each year, three projects were selected to move forward with others likely to be implemented.

The team with the "winning" pitch was able to convince the judges that their solution was not only the best tripe-bottom-line return on investment, but the one most grounded and workable. Winning teams engaged stakeholders for feedback regarding implementing their project, performed a detailed cost analysis based on comparable implementation at similar universities, and documented a significant ROI in each area of the triple bottom line with a breakeven in the investment generally being less than two years.

Student Surveys

Two surveys were done to quantify student outcomes. One survey was done immediately following the "pitch" competition and the other was given as an end of the class exit survey. The exit interview results are more qualitative, therefore the results present in Table 1 are taken after the competition. Three areas of performance using a scale of 1-5 (1=none at all to 5=extreme) were statistically compared to previous year's results. None of the questions presented showed a statistically significant difference over the years. The questions asked were

a. "Rate your overall satisfaction with the leadership development experience"
b. "Rate the level of challenge offered by your leadership development experience"
c. "Rate your increased understanding of leadership concepts"

The results, shown in Table 1, showed no statistically different change ($p < 0.01$) from the first to last year's leadership development experience, despite the changes made in the program. Some improvement was made in terms of challenge overall understanding of leadership concepts.

Table 1. Student Survey Results

	Year 1	Year 2	Year 3	t (1-3)	p (one tail)
$\bar{x}$ (a) and mode	4.58/5	4.75/5	4.46/4	-0.62	0.2703
S (a)	0.51	0.45	0.52		
$\bar{x}$ (b) and mode	4.42/4	4.33/4	4.69/5	1.44	0.0812
S (b)	0.51	0.65	0.48		
$\bar{x}$ (c) and mode	4.33/4	4.08.4	4.58/5	1.02	0.1587
S (c)	0.65	0.79	0.64		
n	13	13	15		

Assessment by Faculty

For the most recent year of the program, assessments of student leadership development were performed by faculty and mentors at multiple points in the program with two specific efforts to convert qualitative observation and analysis into quantitative values in four areas. The two specific collection points were shortly after the teams presented their initial ideas and then following the final pitch competition. The results are shown in Table 2. The four areas assessed on a scale of 0-5 (0=lowest and 5=highest) were in the areas of

(a) their ability to motivate their team (meet milestones and deliverables)
(b) their ability to communicate their vision for the project and team
(c) their ability to listen to their teammates and stakeholders and act
(d) their ability to empower their teammates (getting the team members into the right places and with the right resources to succeed)

Table 2. Results of Faculty/Mentor Assessments

	(a)	(b)	(c)	(d)
$\bar{x}$ (before)	**3.27**	**2.17**	**2.70**	**2.63**
$\bar{x}$ (after)	**4.00**	**3.53**	**3.00**	**3.37**
S (before)	0.65	0.56	0.46	0.69
S (after)	0.42	0.61	0.80	0.64
N	15	15	15	15
T	3.66	6.40	1.26	3.01
P (two tail)	0.00133	0.00002	0.2208	0.0055

While each area showed an improvement in development, as indicated in Table 2, certain areas had greater improvement. In the area of motivation and empowerment, 12 of the 15 students showed improvement, while only nine were judged as improving in listening skills. All fifteen students showed improvement in their ability to communicate a vision to their peers. Additionally, the results shown in Table 2 indicate that a statistically significant increase occurred in three of the four areas, with only the area of listening not improved to a statistically significantly level. While no exact reason was determined for the lack of statistically significant improvement in listening, it was generally felt that they did improve, but that their ability to incorporate the input from stakeholders into their project vision remained problematic.

Stakeholder Feedback

Two surveys were used to gain stakeholder feedback. While the stakeholders surveyed included both students and external participants, the surveys that were returned were mostly from the students. One general survey included questions about lessons learned, descriptions of positive and negative experiences, and recommendations for improvement. Some of the most common feedback included:

- Enjoyment of the opportunity to work with other disciplines
- Project was significant in development as a leader
- Satisfaction in creating a solution to a real-world problem

- Stimulation from the competition
- Request for specific times for collaboration to ensure all can participate, especially University staff that have busy and fluid schedules
- Learning by experiencing the approaches to problem solving from students of other disciplines
- Wanting to see the pitch presentations from other teams (wanting to see all teams in the case of staff survey comments)
- Provision for greater tools for identification of stakeholders and stakeholder access

Conclusions and Future Direction

A sustainability-focused, semester-long, course-based learning experience integrating students across academic colleges was developed and used to help students develop leadership skills. The cross-functional team model was implemented and even with the expected challenges, data indicate that leadership skills were developed. The student survey data did not indicate any statistically significantly different results than prior years, despite the changes in the process. Anecdotal evidence and qualitative responses indicated a higher degree of satisfaction in the process and improved learning outcomes in leadership development. For all years, students indicated they appreciated the tangible connection of leadership concepts to practice through the competition. Direct assessment of student leadership development indicated a statistically significant improvement in the engineering student's ability to motivate, communicate vision, and empower their followers.

In addition to the focus on cross-functional team execution, additional improvements are anticipated for the next year of the effort. Some of these improvements will include

- Providing video feedback with the recorded pitches so that all teams can review the work of others
- Weekly reinforcement of deliverables to not just the engineering students, but to all teammates in a structured environment to increase team contact
- Structural alignment of the three leadership development programs to provide mandatory times for team engagement
- Earlier engagement for identification of stakeholders

Perhaps the greatest takeaway is that significant improvements in assessment methodology is needed to provide greater understanding of leadership development. With most of the structural impediments to the program resolved, and thanks to in-depth suggestions from members of ASEE LEAD, development of an assessment rubric for the direct evaluation of student leadership instead of depending on loose, qualitative inputs will be the first focus. Additionally, more rigorous student pre- and post- survey tools for self-assessment of their leadership development must be developed with the goal of developing techniques that are more effective in helping the student's improve their leadership in the four targeted areas.

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