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A Project-Based Approach Professional Skills Training in an Undergraduate Engineering Curriculum*

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STEM leadership education as a formal discipline is not present in the majority of higher institutions. Similar is the case with ethics in engineering schools. Although ethics is recognized as a crucial aspect in developing the professional identity of engineers, it is still not required as a mandatory course in all engineering curricula. This study introduces a project that simulates a real-world engineering application and uses this task to examine how the assignment objectives influence employment of students' leadership skills and social responsibility awarness. The participants were from three different groups – (1) learning communities, (2) traditional sections, and (3) international sections. It was hypothesized that there would be different outcomes of the students teams projects considering the three different missions of the groups. Results corroborated the hypothesis. The learning community teams proposed projects that best addressed the assignment objectives and enhanced professional skills in the utilization of the course project compared to the traditional and international sections. Outcomes are discussed in terms of underlying links in assignment objectives and the enhancement of professional skills in engineering instruction.

Keywords: engineering leadership; ethics; engineering education; project-based approach

1. Introduction

1.1 Motivation

Many centuries ago the Greek inventor Archimedes needed only a place to stand and he claimed he will move the Earth. Nowadays, scholars confront that only "knowledge isn't enough" arguiing that "the potential to wield such power is accompanied by equally weighty social responsibility that such obligation today is becoming ever more pressing and complex", pg.52 [1]. This view is supported by the the United States engineering accredition body, ABET. According to ABET's code of ethics, "engineers uphold and advance the integrity, honor and dignity of the engineering profession by using their knowledge and skill for the enhancement of human welfare; being honest and impartial, and serving with fidelity the public, their employers, and clients; and striving to increase the competence and prestige of the engineering profession", pg.1 [2]. Engineering programs are designing curriculum based on ABET educational outcomes to help students develop knowledge and abilities related to the ability to function on multidisciplinary teams and understandings of professional and ethical responsibility [3]. In accordance with ABET, the National Academy of Engineering highlights disired attributes for future engineers to include strong analytical skills, creativity, ingenuity, professionalism, and leadership [4].

As part of this effort, engineering colleges and universities have begun to offer engineering leadership education in the form of classes, certificates, and minors. However, leadership education as a formal discipline within science, technology, engineering, and mathematics (STEM) is not present in most higher education institutions. Similar is the case with ethics in engineering schools, despite the fact that ethics is recognized as a crucial aspect in the professional identity development of engineers. In addition, most undergraduate engineering curricula offer little opportunity for teaching and learning ethical behaviors, responses, and attitudes in a systematic and pedagogically appropriate manner [5]. These and other traits such as strong analytical skills, creativity, ingenuity, professionalism, communication, and leadership remain important to companies where future engineers will be expected to demonstrate a variety of technical and nontechnical skills.

1.2 Background

Literature shows that the pedagogical framework of

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engineering ethics education has evolved primarily toward utilization of case studies and codes of ethics, and in some instances has been supplemented by an introduction to moral theory [6–8]. Substantial progress has been made in the development of case study materials, including high profile and everyday cases. According to Ohland and Barry [9], within the literature associated with the engineering profession, there is much discussion and debate over appropriate real-world instructional methods and the incorporation of such methods in engineering curricula. The use of case-based instruction methods appears to be the most common pedagogical method within engineering ethics education [7]. Research related to professional ethics within engineering has primarily focused on the assessment of student learning, rather than an evaluation of instructional methods and/or curriculum incorporation methods.

The pedagogical framework for leadership education is similar to ethics education as in recent years professional ethics is viewed as part of leadership attributes and abilities of professionalism. For example, reviewing the curriculum of the Massachusetts Institute of Technology's Gordon Leadership Program, one of the leading programs offering leadership education in engineering schools in the United States reveals a curriculum with an emphasis on engineering effectiveness and active career design [10]. Via hands-on exercises, students engage in engineering specification, project engineering, negotiation, and ethical implications of engineering decisions. Students are also exposed to key success factors for professional engineering by practice via networking, business communication, and reputation building. Faculty and industry professionals help students to apply these concepts by guiding them as they apply for summer internships in industry, government, and the nonprofit sector. Students receive instruction and individual coaching before, during, and after their internships, to help them locate and negotiate the terms of their hands-on summer work and to ensure that their future job success.

In designing learning activities and choosing appropriate pedagogical approaches, we cannot ignore the learner and her/his background, interests, and abilities. Scholars suggest that when teaching professional skills, several issues must be considered. First, students have to be motivated to take seriously the opportunity to learn and to excel in such areas as ingenuity, professionalism and leadership, especially since these traits are not focused explicitly upon traditional engineering curricula. Students need to be convinced that courses and/or assignments are intended to encourage moral reflection and leadership practice, no just simple recitation of facts and materials. If opportunities are presented for students to reflect on realistic, engaging cases in ways that respect their moral capabilities, we anticipate that they will sense that they are being respected by their instructors as moral agents and thinkers in their own right.

Second, many students have a difficult time dealing with too much complexity, which is often dealt with by creating models. While models are necessary, it is also necessary that engineering students understand the differences between models and real life along with the importance of selecting appropriate models for various situations. Usually, the cases used as models in teaching engineering ethics are reflections of large ethical problems that arise infrequently in engineering rather than ordinary circumstances. One way to overcome this contextual concern, however, is to limit extraordinary cases' uses within the classroom and to focus primarily on cases inspired by real, everyday examples. As instructors, we have observed that when students use their own projects as examples to identify a possible ethical issue and to exercise ethical and leadership thinking, they are usually more engaged than when working on case studies; thereby students may take increased ownership of their learning. Relative everyday examples can help students understand that the decision making processes in ethics and leadership are not very different in what they are doing in the engineering design process [5].

The American Society of Engineering Education (ASEE) recommends integrating the student curriculum at all educational levels (i.e., K-12, undergraduate, and graduate) with design experiences [11]. They note that "it is equally important that students have design-related experiences early in their academic careers and not wait for the senior design capstone experience to do real engineering", pg.18 [11]. Pedagogical approaches such as problem-based learning and project-based learning are instructional approaches that feature complex, ill-structured, open-ended real-world problems [12]. In problem-based learning, students are confronted with an ill-defined problem and work in teams to find a solution. Instructors act as facilitators of real-world problems that can require single or multidisciplinary collaboration. In project-based learning, students are either given or choose a project and design an approach to complete it. Evaluation of this method shows that relative to lecture-based instruction, students who participate in project-based learning are more motivated, demonstrate better communication and teamwork skills, and have a better understanding of issues of professional practice [12].

Learning through the exploration of problematic situations is not a new educational approach. If we trace the origins of problem-based learning back to early educational forms, we will see that Socrates presented students with problems that, through questioning, enabled him to help them explore their assumptions, their values and the inadequacies of their proffered solutions. In *Problem-Based Learning in Higher Education: Untold Stories,* Savin-Baden [13] argues that this kind of increased understanding and examination of perspectives and frameworks is encouraged through problem-based learning, because it offers students opportunities to examine their beliefs about knowledge in ways that lecture-based learning and narrow forms of problem-solving learning do not. More than a century ago, John Dewey, the father of educational philosophy, argued that instruction should be based on students' interests, where students are involved in real life activities and challenges [14]. Dewey's views on this were played out in practice by his emphasis on learning by doing, which can be seen as a problem-solving or service-learning approach to learning.

Most of the literature on service-learning argues that this form of learning benefits students with increased commitments to democratic values and social justice [15]. Students who are involved in service-learning projects identify opportunities to engage in community service as contributing factors to their interests in project participation. Students report that some of the valuable things they learned in service learning projects are professional skills such as communication skills, teamwork, project management and planning, leadership skills, community awareness, and engagement with ethical issues [16]. In addition, through service-learning, first year engineering students learn how science is applied and what the engineering profession entails [17].

In summary, the pedagogical importance of inductive learning methods such as project-based learning and/or service-learning could create environments where students are driven by their passion, curiosity, engagement, and dreams. Students will be given the oportunity to understand and to adapt to professional engineering standards and to values of the community via observations and actions similar to those of actual engineers. For this reason, course activities and materials need to be aligned to learning goals and with course content, assessments, and desired pedagogical principles and practices [18].

1.3 Purpose of the study

This research examines the processes that promote or undermine students' professional skills in regards to leadership and social responsibility within stimulating academic situations that incorporate project-based learning and service-oriented themes. In the study, first year engineering students were given opportunities to choose a project theme with a focus of helping their communities (e.g., how to help elderly people in farms away from town) and to design approaches (e.g., propose a solution, design a product, write a report, or educate community members) for completing their projects. The project needed to simulate a real-world engineering application. We used this task to examine how the assignment objectives influence employment of students' professional skills. We also investigated whether there were any differences in projects' outcomes based on the student groups' cultural background and the different missions of the three groups.

2. Presentation

2.1 Participants

The participants were 407 first-year engineering students enrolled in a weekly, one hour introductory engineering seminar at a Midwest university in the United States in the fall of 2012 semester. To accommodate the diverse student populations of students at the university, the course contained three different groups with multiple sections per group: (1) 9 *learning community* (LC) sections (126 students took this introductory seminar, an engineering problem-solving course, and a communications course as part of a cohort); (2) 10 *traditional* sections (201 students only took the introductory seminar together); and (3) 4 *international* sections (80 international students were enrolled together in only the introductory seminar). In addition to attending three of the same courses during their first semester at the university and live in the same residence hall, LC students engaged in a larger university LC program focused upon enhancing first-year students' learning and success via out-of-class co-curricular activities, service-learning experiences, and related field trips. The international sections allow incoming international students to interact academically and socially with each other, and to interact with peer mentors who could help international students to make successful transitions to the College of Engineering and the USA. Traditional classes included U.S.-born students with a focus on helping students successfully transition to their respective engineering departments within the College of Engineering.

2.2 Course description

The course involved in the study is a one-credit hour, letter graded first-year seminar that has been taught for several years at the university. Students meet once a week for fifty minutes in small groups of fourteen to twenty students per section. The classes are led by upper-division engineering peer mentors who receive training from College of Engineering faculty at the university through their own one credit course that emphasizes the establishment of a mentor-mentee relationship. The essence of the first-year seminar course, however, is to help first-year engineering students successfully transition to their respective engineering departments within the College of Engineering, including learning about engineering coursework that provides the background for engineers to succeed as practicing engineers. In the first part of the class, peer mentors usually deliver practical content (e.g., time management and overviews of each engineering discipline) and mentoring (i.e., how to prepare for exams, how to choose an engineering major that is right for them, and where to look for academic advice). The learning styles across sections are very much liberal and flexible. Course assignments are designed to help students learn about university resources, ways to prepare them to participate more fully in all of their classes, how to reflect on their peer mentors' advice, and ways to engage in different engineering fields. Prior to fall 2012, the course's final project required first-year students to work in teams to engage and develop an engineering product that would be of interest to middle school students. They focused on discovering how engineers have contributed to the development or improvement of the product and what engineering coursework provided the background for engineers to work successfully within a company manufacturing the product. This course major assignment aligned with one of the course learning objectives that focused upon students gaining a realistic perspective of what it takes to succeed as an engineer.

2.3 Rational for the project

In fall 2012 the instructor of the course decided to bring, in alignment with ABET critiria and the U.S. National Academy of Engineers' policy reports, ethical awareness and leadership skills to students' first engineering academic experiences, especially since a realistic perspective of successfully practicing engineers includes not only technically proficiency but essential atributes such as "being a global citizens, leaders in business and public service, and who are ethically grounded" [4, pg.51].

The course instructor also wanted to incorporate the university's common reading book that was read by incoming first-year students at the university. Focused on the story of a young man who serves his community while learning by inventing, *The Boy Who Harnessed the Wind*, by William Kamkwamba, is a book about a young man who uses the only resources available to him to build a windmill to improve the lives of the people in his community. An example of intuition, inventiveness, imagination, ingenuity, initiative, and determination, the story is one of hope and the power of one person to transform a community [19]. This reading also provides a common intellectual foundation for faculty, staff, and students and aligns with the university's strategic goal of producing tomorrow's leaders and global citizens. Other themes of the book include consideration of cultural and environmental impacts, self-determination, community development, and usage of common materials to produce engineering innovations.

2.4 Overview of the project

All students in the course (27 teams across learning community sections, 52 teams across traditional sections, and 19 teams across international sections) were assigned to work on a final engineering project called "Hunting for Good". Developing engineering products and solutions using materials "common", e.g. available in their communities' students were encouraged to be more sensitive and observable of what was around them and to identify ways that their ideas could be utilized to help the local community. Students also were given the opportunity to choose to do a research project about natural disasters that have happened in the area along with the causes and how students could protect their communities during such a disaster. The teams were not limited to a fixed issue but were encouraged to explore things that they were passionate about (for example, if someone likes to do computer programming or enjoys biology) and to utilize their skills and strengths when choosing the idea of the project. Considering that they worked in teams, students needed to develop projects that considered all team members' passions and/or skills. For the four sections of international students, an option of developing engineering products and solutions to serve their community was provided. The instructor also required that student teams incorporate consideration of diverse cultural perspectives. An example of the alignment of one of the course learning goals with content, assesment, and the pedagogy (CAP) is shown in Table 1.

For the assessment rubric in the course outlined in this paper, Pellegrino's Assessment Triangle was used where "reasoning about students' knowledge from evidence obtained in an educational assessment is portrayed as a triad of three interconnected elements – the assessment triangle", pg.44 [20]. The Pellegrino triangle has three key elements underlying any educational assessment: (1) student cognition and learning; (2) observations that provide evidence of students' competencies; and (3) an interpretation process for making sense of the

Table 1. Alignment of Introductory Engineering Course's Content, Assesment, and Pedagogy

Content (Learning objective)	Assessment	Pedagogy
Students have a realistic perspective of what it takes to succeed as an engineer, including:	The common reading book Guess speakers Summative and Formative assessment	Discussion Debate Reflection
a. Students will exerciseethical thinking (social responsibility, diversity, serving the community)	Group Project- Students will work in small groups to prepare a project proposal	Active learning Group work
b. Students will practice Leadership role (communication, team work, planning, organization, leading)	Working in their class groups (i.e., learning community, Traditional, International)	Cooperative Learning
	Final proposal Evaluated through the rubric	Exploration of the knowledge Transfer
	Presentations Formative assessment	Reflection on the process Transfer

Table 2. Learning Goals and Assessments

Students will exercise their ethical thinking	*Claim:* Students will be able to use their ethical thinking.	
	Task: Students are working in teams to develop a project that will help their communities.	*Evidence:* Students will describe how the development of their idea and/or proposal will help their communities.
Students will practice leadership roles	*Claim:* Students will be able to practice leadership roles.	
	Task: Students will take leadership roles into consideration in the development of the proposal.	*Evidence:* Students will provide evidence of each member's contribution to the project.

evidence. In the Assessment worksheet below, the alignment between the course objective and assessment is presented as well (Table 2).

2.5 Evaluation

The project outcome needed to serve the community of teams' choosing. Along with an evaluation of student teams' technical expertise, the project grading rubric contained the following criteria: leadership, social responsibility, the use of common materials, creativity, team effort, and diversity (Fig. 1). Students were rated by evaluators (described in a subsequent section) on a 5-point Likert scale such that "1" meant that the attribute was not present and "5" meant that an attribute was present. The maximum score that a student team could achieve was 50 points.

Hypotheses: It was hypothesized that there would be different outcomes of the students' team projects considering the three different groups in the class (i.e., learning community, international, and traditional sections). It was also hypothesized that the different outcomes of the final project would be related to each group's mission.

Projects were presented at the end of the semester. The instructor of the course invited engineering faculty and peer mentors to witness all teams' projects presentations. In two days, 98 teams presented their final projects, thereby creating an oportunity for all students to hear what their peers worked on and to learn from each other. Each team was rated by three evaluators—the course instructor and two peer mentors accociated with partcicular section teams. Reliability was calculated by comparing the number of agreements and disagreements of each rater with the evaluating criteria and by calculating the average percentage of agreement. Reliability was found to be 82% across projects.

3. Findings

The goal of the analysis was to examine if there are significant differences in the performance of the teams of the three different groups. To test the hypotheses, we utilized a combination of quantitative descriptive statistics and qualitative approaches to describe the project outcome of specific teams in relation to their group missions (i.e., cohort-focus for learning community (LC) sections; successful transition to students' respective engineering departments for traditional sections, and a global focus for international sections). The unit of the analysis in this study was the team with the maximum total score for team performance being 50 points.

Overall, LC teams had the highest average score (47) folowed by the teams from the traditional

A brief **history of the product/idea** focusing on how it has evolved including: 1) technological advances that could make the idea/product possible and 2) the use of common materials

5 (Yes) 4 3 2 1 (No)

A brief description of **what this product/idea** is about related to:

Creativity – originality of the idea/product

5 (Yes) 4 3 2 1 (No)

Technical expertise – technical knowledge to show evidence that this idea/product will function

5 (Yes) 4 3 2 1 (No)

Team effort - how the members of the team contributed to the project

5 (Yes) 4 3 2 1 (No)

Points in this category are given for the following:

Description of the **job functions** each type of engineer could have during the development of the idea/ product

5 (Yes) 4 3 2 1 (No)

Description of how the development of this product/idea will **help/serve the community**

5 (Yes) 4 3 2 1 (No)

Description of how the proposed idea/product will benefit **diverse** populations

5 (Yes) 4 3 2 1 (No)

Overall have the students used good intuition, inventiveness, and showed open minded approaches and integrity in the proposed idea/product to help/serve their communities?

5 (Yes) 4 3 2 1 (No)

Fig. 1. Final Project Evaluation Rubric.

group (44.80) and the teams from the international group (44.60). The highest average score of 49 was found in a LC team that clearly addressed the needs of the community and produced a solution benefitting a diverse population. Ironically, the lowest score across teams was 40 and was also found within a LC team. Unlike the highest scoring team, this team did not address community and diversity needs. The best projects with total maximum scores (50) were a team from the traditional group and a team from the international section. Both teams demonstrated global thinking, created a decision matrix, and used professional design software to introduce their ideas.

The topics varied greatly across groups (Table 3). LC topic proposals were most similar across groups.

Table 3. Groups' missions and Examples of Teams Projects

Group	**Mission**	**Project Theme Examples**	**Variety of Topics**
Learning Communities	Take courses as a cohort, retaining students, enhance students' appreciation of diversity and multiple perspectives, engage student in their chosen major, increase students' ability for diagnosing and addressing their learning needs, potential to facilitate service-learning	Bike Rack Bed Ladder Long Boar Rack Improving Desk Space Padlockers for mailboxes	7
Traditional	Successfully transition to students' respective engineering departments within the College of Engineering	Heat Loss Self Sanitary Environment Wellchair accesibility Reduce-Reuse-Recycle Solar Energy Speed Bump Generator Heated Rotational Bench Water for Gana Foot Power Weather Shelters Open Doors Easier Picknic Area Water Fountan	19
International	International students to interact academicaly and socially with each other, to interact with peer mentors who could help internatianal students to make a successful transitions to the College of Engineering and the USA	The Hand-I-Helper Building a Column Still Recycable rain Ponchoes Piezoelectric Key Privicy Issues Suction Board Raining Bike System Electricity Generated Bikecycle	14

For example, from 27 teams from the LCs, six teams chose to design bicycle racks to house bicycles for students on campus, and six chose to design skateboard racks to house students' skateboards compared to the traditional and international groups. Within the traditional groups, topics include Self Sanitary Environment, Solar Energy, Heat Loss, and Wheelchair accessibility that represented Environmental, Energy, and disability concerns issues. Finally, the teams from the international sections may have scored lowest on average but had the best presentation of history of their products, including cultural and worldwide applications. At the time of the presentations some of the students shared that they took pride in doing the project and had a great experience being on international teams and overcoming language issues.

4. Discussion

Initially, most of teams struggled in the identification of their projects. Many students did not understand what common materials were, and many teams did not readily identify opportunities for being socially responsible. When asked to use common materials, students were advised that they could consider materials such as recyclable materials, natural resources, culturally relevant items, and loose and unused parts. To help students have more clarity on the project objectives, the course instructor elaborated on the project outcomes by proving more rationale: "There are fields of corn and soybeans that need to be stored for the winter; there are uncovered roads; elderly people in farms away from town; closed, unused pipes in the middle of the fields; etc".

The students were reminded that the final outcome of the project was only a proposal for the product and/or solutions the teams would develop, not a prototype. The teams needed to convince the project evaluators that their projects were worth funding. The common reading book was used as a great example of intuition, inventiveness, imagination, ingenuity, initiative and determination. Again, the students were encouraged to be open minded, use good intuition, to be inventive, and not to be afraid of taking risks, as sometimes these are the best and most revolutionary ideas.

Findings confirm that many of the topics align with the missions and goals of each of the groups. Since the purpose of the LC was to create a common, cohort experience among engineering students across three classes, it is not surprising that this group had the most replicated and similar projects across sections. Such a cohort experience and familiarity across teams could have indirectly limited students' creativity and exploration of diverse topics. This is supported since the highest average score across groups in areas such as leadership or diversity came from the traditional and international groups. Students in the international sections produced projects that reflected global perspectives. Unlike students who may not have as many creative ideas about how to produce solutions that are more nontraditional in nature, international students benefitted from exposure to materials and experiences that reflected a non U.S. culture, and therefore flourished in the areas of leadership, team work, and overcomimg language barriers.

Our study suggests that it might be necessary to guide first-year engineering students more deliberately in the development of open-ended projects. It might be helpful for instructors to define projects with a scope appropriate for the course considering that most first-year engineering students do not have design experience and proposal writing expertise related to projects, products, or services. While it is important to introduce and to build professional skills in the very first year of college, engineering educators should consider that students need more guidance and structure when working in groups, especially groups that connect diverse students. We observed that despite the best intentions of the instructor to introduce the students to professional skills, students had difficulty perceiving the project as opportunities to practice leadership and to exhibit social responsibility. This led to the conclusion that mixing project-based and service-based learning approaches within instruction could hinder implementation of both methods. In regards to the creation of technically sound projects, we hoped that students would apply material that was already somewhat familiar to them; however, they needed guidance throughout the semester to function as efficient teams. It would be helpful to guide peer mentors more explicitly as they facilitate this type of instuction for first-year engineering students. Finally, since it might be possible that many of the students have never experienced any diversity outside of their own communities, additional demographic questions might be added in the future to explore the initial exposure that students have had to such ideas.

5. Conclusions

To improve course instruction and to include professional skills training in first-year engineering curricula, we attempted to investigate how the assignment objectives of a real-world engineering project influenced employment of students' leadership skills and social responsibility awarness. It was hypothesized that there would be different outcomes of the students' team projects considering the three different missions of the groups. Results corroborated the hypothesis. The learning community teams proposed projects that best addressed the assignment objectives and enhanced professional skills in the utilization of the course project compared to the traditional and international sections. Our exploratory study also supported the view that project-based learning and/or service-learning creates environments where students are driven by their passions and curiosity and can be engaged in activities to understand and to adapt to professional engineering standards and to values of the community via observations and actions similar to those of actual engineers. The course activities and materials were aligned to the learning goals, the course content, assessments, and the pedagogical approach. There were not statistically significant differences across the three groups, so we can not make claims of what could be best practices in first-year engineering seminars when mixing sections with students with different cultural, academic, and demographics backgrounds. Raising this topic in this particular way, however, we are hoping that engineering educators who are maintaining a course with such settings consider including different options of teaching and assessing students' professional skills and evaluating course outcomes. We hope that engineering educators will find this study useful in defining specific objectives for course work within their programs as they seek to prepare future engineers with complex attributes such as strong analytical skills, creativity, ingenuity, professionalism, and leadership. Future work includes the development of a longitudinal study investigating the benefits of project-based learning to the development of professional skills in engineering education.

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