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The Complete Engineer: How the Whiting School's Engineering Management and Leadership Course Complements Senior Design

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Introduction

According to the Accreditation Board for Engineering and Technology (ABET), STEM graduates must be "prepared with the knowledge, skills and aptitudes to meet workforce demand" [1]. ABET adopted Engineering Criteria 2000, updated several times since, that focused on what students learn rather than what programs teach. The new framework included skills such as "critical thinking, communication and teamwork" [1]. The guidelines are influenced strongly by industry workforce needs as hiring managers turn to ABET-accredited programs because they know graduates will have certain skills based on student outcomes" [1].

To prepare students for engineering work after they graduate, especially as they become "innovators (who) seek out new solutions to problems facing our society" [2] many universities offer experiential coursework, such as senior design (a required team-based capstone project), and extracurriculars (e.g., Baja SAE and Design, Build, Fly competition teams). These activities and courses provide the collaborative, hands-on, meaningful application of engineering learning that students need. Explicit instruction in team citizenship, shared leadership, and project management as well as the other capabilities and knowledge needed by working engineers is usually beyond the scope of these courses and experiences, yet are critical to the *complete engineer*.

To support students' learning on these interpersonal, professional, and other non-technical work capabilities, the Whiting School of Engineering created the course Engineering Management & Leadership (EML). Here is an excerpt from the course description:

> *When engineers become working professionals, especially if they become team leads, managers, or entrepreneurs, they must juggle knowledge of and tasks associated with team citizenship and leadership, ethics, strategy, operations, finance, and project management. While engineers' success may depend on their own direct input, managers'*

success depends on their ability to enlist the active involvement of others: direct reports, other managers, other team members, other department employees, and those above them on the organizational chart. Sometimes even their suppliers or customers! In this course, you will learn about teamwork and people management, and gain an introduction to strategy, finance, and project management. You will practice writing concise, persuasive analyses and action plans and verbally defending your ideas.

ABET student outcomes are listed below in Table 1 [3]. Outcomes that are taught and assessed in EML are denoted in the table:

Table 1. Student Outcomes taught in EML:

ABET #	Student Outcome	Taught in EML course
1	an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	N/A
2	an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	Some examples addressed in cases and discussions; assessed through assignments and in-class comments.
3	an ability to communicate effectively with a range of audiences	Taught and assessed using case memos (to a hypothetical work colleague), class discussion, and presentations (to peers and instructors).
4	an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	Taught and assessed through readings, case memo assignments, presentations, and in-class comments.
5	an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.	Taught and assessed through readings, lectures, in-class activities, group assignments and a peer review system with rigorous and thorough feedback.
6	an ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgment to draw conclusions.	N/A
7	an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.	Taught but not assessed; in-class discussion intentionally focuses on how adults learn

		and the criticality of continuous learning.

As a complement to senior design or for those students engaged in a project, EML is designed to prepare students for work relationships and responsibilities when they graduate, and to support the engineering departments in meeting ABET interpersonal and communication requirements. Over the last 12 years, the course has grown and now is required or strongly recommended for fourth-year (senior) students in four majors: Mechanical Engineering, Material Sciences & Engineering, Civil Engineering, and Systems Engineering.

EML is taught during the fall semester of each academic year in small sections to foster student engagement. The course provides meaningful exposure to real-world challenges that engineers face – from ethical scenarios and project management situations to multidisciplinary teaming. In alignment with ABET, this course is designed to allow students to "learn beyond the theory in a way that can make them better problem solvers for life" so that "when students graduate, they will be confident in their abilities, well integrated into the industry and have the skills to excel" [2]. Drawing from ABET intended outcomes and the needs of early career engineers, this qualitative study explores how undergraduate students apply what they learn in the EML course in curricular (i.e., senior design projects and other significant university projects) and non-curricular ways.

Literature Review

Evaluating the effectiveness of university engineering programs has been critical to the development of global engineering education in the last 30 years. Engineering Criteria 2000 (EC2000) is an accreditation criterion introduced by ABET in 1996, evaluating all American engineering programs since 2001 and recently extending to international universities (Felder & Brent, 2003). The ABET outcomes encompass critical technical and non-technical skills for college students, ranging from the ability to apply knowledge of mathematics, science, and engineering to the ability to function on multidisciplinary teams [4]. The implementation of

ABET criteria has led to statistically significant improvement in "awareness of societal and global issues…group skills… and awareness of issues relating to ethics and professionalism" while maintaining and even improving students' understanding of the foundations of engineering as found in a study comparing 1994 and 2004 engineering graduates [5]. Research suggests that ABET outcomes be taught through traditional lecture courses, laboratory courses, and project-based learning such as capstone and cornerstone projects [4]. Some ABET outcomes, for example 3,4, 5, and 7 (as denoted in Table 1), can be perceived as less technical, focusing on abilities such as communicating "effectively with a range of audiences", functioning "effectively on a team", and recognizing "ethical and professional responsibilities in engineering situations and [making] informed judgements" [1]. Supporting ABET's teaming outcomes, research shows that to succeed in industry, engineers must have multidisciplinary teaming skills, such as the ability to "communicate clearly and respectfully to those outside of one's own discipline" and to "adapt quickly to different work and communication styles" [6]. Rather than solely restructuring existing courses to address these outcomes, select universities have introduced a wide range of engineering management and leadership courses and programs. The effectiveness of such curricula has not been extensively evaluated.

Project-based learning (PBL) has been the most successful and critically evaluated of the aforementioned instructional methods. Universities tend to implement project-based learning styles to achieve ABET outcomes as it provides students with "authentic, valued skills for engineering practice" through required laboratory courses and projects [7]. Studies have demonstrated that project experiences result in statistically significant increases in students' self-confidence in professional, interpersonal, and open-ended problem-solving skills [7]. The implementation of PBL has also resulted in clear improvements regarding soft skills like teamwork and responsibility; one study in Spain found that 71% of students had a positive perception of key skills gained through the large projects such as "teamwork, autonomous learning, and responsibility", critical components of ABET outcomes 5 and 7 [8]. Cornerstone projects are those in which first-year students undertake a team-based project. They are more focused on conceptual design methods and as a PBL experience, are critical in addressing transfer, the ability to extend content learned in one context to other, new contexts; essentially

ABET outcomes 2 and 7 [9]. Cornerstone projects at universities such as Harvey Mudd, Northwestern University, Pennsylvania State University, University of Colorado at Boulder, and many more demonstrate that PBL "encourages and supports collaborative work and that it improves retention and enhances design thinking," fitting the requirements of ABET outcomes 1, 2, and 5 [9]. Furthermore, another study demonstrates that "PBL was more helpful in improving high-level engineering skills than the [traditional learning] with considerable increase in mean scores" [10]. Zhang and colleagues saw statistically significant increases in critical thinking, creative thinking, and advanced engineering skills [10].

The success of PBL in addressing ABET outcomes is clear; however, there seems to be a lack of literature discussing how concepts relating to product decisions, customer needs, leadership, decision-making, and engineering ethics are taught through these PBL experiences. In addition to design teams, select universities have developed engineering management and leadership courses to address this gap. However, engineering management and leadership courses have not been as widely adopted as PBL in addressing ABET outcomes, perhaps for two reasons. First, it is more challenging to develop and implement these programs as engineering students often do not see the value of leadership and management education as compared to more technical course aspects. Non-technical education is perceived as less useful; necessary only for management, rather than research, entrepreneurship, and traditional pathways [11]. Additionally, there is an apparent lack of literature regarding the effectiveness of these courses. Drawing from ABET intended outcomes, this study aims to shed more light on the impact of engineering management and leadership courses for undergraduate students and their impact on students' senior design and other significant university projects.

Methods

This study employs qualitative methodology, using focus groups, to explore the impact of the Engineering Management and Leadership course on undergraduate students. Undergraduate engineering students, in their junior or senior year of study, enroll in the EML course. All students enrolled in the Engineering Management & Leadership course during the Fall 2022 semester were eligible to participate in the study. All but one student (N = 52), due to enrollment

status, received an email invitation to participate after grades were posted to protect against any inducement. Six students, representing 11.54 percent of the population, consented to study participation. To reduce self-selection bias but not overly influence participation, each participant was offered a $10 gift card as an incentive. Institutional Review Board (IRB) approval was obtained to demonstrate commitment to ethical research. The participants were given disclosures that explained the confidentiality at the beginning of the focus group. All participants were offered an opportunity to review the final report.

Data Collection

Data collection for qualitative research usually involves direct observation, participating in the setting, interviewing individuals or groups, or analyzing documents and other materials [12]. This study employed focus group methodology, which allowed for open interaction, sharing, and development of common meaning between participants [12] [13]. This methodology supports the research aims of this study. The researcher probed with stimulating questions while encouraging group discussion and only intervened when the discussion departed from the intended direction.

Data (n = 6) was collected from two 60-minute online focus groups, in February 2023, using semi-structured, open-ended questions. Focus groups were recorded and transcribed verbatim using a third-party service. Transcripts were reviewed by independent researchers. After review, the researchers met to discuss and confirm codes. Discrepancies were discussed until consensus was reached. Finally, the researchers collectively developed the themes.

Results

Results suggest that undergraduate students enrolled in the EML course experienced several benefits. Students shared their overall perceptions, how the EML course prepared them to better manage their senior design and other significant university projects, and how they gained skills that extended beyond the classroom. Where appropriate, data that aligned with ABET outcomes is denoted.

Course Perceptions

Study participants shared their overall perceptions of the course by sharing one word that described the course, which includes "hands-on, relevant, applicable, self-awareness, beneficial, and helpful." One participant summed up the overall value of EML with the comments of former students who came back to visit:

> *... I think three or more, have-- when I asked about what the most influential class was at the [university] they said, "It was [the] EML class... They were three to eight-year-plus alumni. And that was the most influential class that they had at Johns Hopkins University. So I guess it is relevant both in industry and in grad school.*

> Another participant said the course content is *"definitely something I hope to keep in my back pocket for whatever comes up".*

Senior Design and Other University Projects

There were many comments about how the course supported their Senior Design projects. Students agreed that they used what they learned. Two participants described the benefit of taking the EML course while simultaneously engaged in Senior Design:

> *And going through this class simultaneously with our engineering Senior Design ... I feel like I was able to utilize what we learned in the class the same weeks.* (ABET 7)

> *Being able to make suggestions to (my Design Team) and saying, this is what I'm learning in this class right now about team management and leadership. Maybe we should try this. We have issues with this last time. We should communicate about this. Being able to just be comfortable with the idea of talking to team members and trying to actively find solutions and, yeah, sharing what I've learned about team management with them and seeing if that would help, and it did.* (ABET 3, 5, 7)

Another participant shared how they used what they learn to overcome challenges with their team:

> *... by using what we learned, it helped us move forward as opposed to reaching a standstill of some sort (in Senior Design project). And if we just didn't have this class, I don't think we would be able to continue as well as we did last semester.* (ABET 7)

> Three participants discussed managing conflict:

> *I remember specifically at some point last semester we were all kind of dying because ... we didn't really have our priorities straight and ... each of us thought we should be focusing on a different thing. I think ... understanding that everyone's going to have*

> *different opinions, and that's part of where good ideas come from … we need to understand how to actually respond to that productively.* (ABET 3, 5)

> *We were very aware of the consequences of these conflicts if they're not addressed pretty much immediately ... for a more recent conflict, it was just bringing up the conflict and then making sure that each team member knew it was nothing personal, and there were no emotions attached. It's more like, "Hey, we need to get something done. This hasn't been done. So let's get it done." So yeah. Just being very objective with our conflicts.* (ABET 3, 5, 7)

> *… we talked about … not assigning particular attributes to people based on their actions, just recognizing that those are their actions and not who they are. If someone isn't doing work on the team that they're supposed to be doing, it's not necessarily that they're being lazy. It's just something that they're doing isn't working for the team. Or if someone says something rude in a team meeting, it's not that they are a rude person. They just said a rude thing, and so you're not growing animosity between your teammates because you're just assuming, 'Oh, this guy is just rude, and he's the worst, and whatever.' So that sort of thing, I think, has been helpful for me. And not just in class conflicts, or working with team members, but just generally in life just taking a step back and recognizing, 'Oh, did my words not come across the way that I intended them to? And this person is doing something that I find to be upsetting.' But it's not them exactly that I'm upset about. It's how whatever their actions are doing are affecting me.* (ABET 3, 4, 5, 7)

Another participant described a psychologically safe environment:

> *… as a Senior Design team, we were able to maintain a psychologically safe environment where we were able to just talk things through, be as objective as possible, and just plan out for the future how to avoid a situation like that but still being honest with ourselves, accountable for everyone.* (ABET 3, 4, 5)

Non-curricular benefits/Beyond the Course

Participants shared how the EML course was helpful beyond Senior Design and other curricular projects. Several participants mentioned how they applied their learning to campus clubs and employment:

> *I also have a job where I have to train people. It's just leading by example a lot of the times. Because [of where] I work... it's just teaching students how to fix things. So I try not to come from a condescending tone when I'm telling them how to fix something. I try to see them as competent and just ask questions like, 'Oh do you know how to do this?' And if they do, I don't try to over explain [or] show that I'm way more competent than them because that's not the goal.* (ABET 3, 4, 7)

> *… last semester, I had just come into a leadership position for a club … And I ... was kind of spinning my wheels a lot…It was kind of a big task, and I was doing a lot of the work myself, and it was just kind of impractical at some point. But pretty early on in the class, we were learning about these leadership ideas and theories and ... we did like a self-*

> *analysis on what kind of leader we were and what bits we need to work on. That kind of helped me realize how I can properly delegate tasks and get help from other people in the club and actually run things a little bit smoother, have things actually kept done on time … Our club has taken on a lot more projects since we just have a lot more people, and I have completely given other people entire leads on these projects, right? So I've kind of made an organization out of the club now instead of it just being a bunch of random people working on different projects, and I'm kind of trying to have a hand in all of them and lead all of them … And so it was kind of actually getting that people management thing, and now that we have enough people in the club to do that, now that the club's revived, now that we have a lot of projects to do, actually applying that and having it run nicely, it's kind of gratifying to see.* (ABET 3, 5, 7)

In addition to EML applicability beyond the classroom, specifically in clubs and employment, participants also mention interviewing skills and career preparation. Two examples from participants follow:

> *... for interviews, for thinking about my resume, for thinking about how I talk about my experience, the things that we learned in EML have been super helpful. [It was also helpful to learn] what to expect in terms of an industry career.* (ABET 7)

> *… the [SMART goal] tool has been very helpful ... if you're talking about something in an interview. I know I've used that.* (ABET 7)

Discussion

This qualitative study explores how undergraduate students apply what they learn in the EML course in curricular and non-curricular ways. This study demonstrates an effective way to help achieve many ABET student outcomes. Findings show that after completing the EML course, students gained important professional, non-technical skills and were better prepared to manage their senior design and other significant university projects.

Participants shared the importance of building an effective and successful team – one that manages conflict and expectations and builds a psychologically safe environment. Students expressed how they applied their learning on teamwork extensively, including communicating clearly and concisely, collaboratively writing, behaving in ways that support team productivity, empathizing across disciplines, and influencing others. In fact, nearly every participant had an

anecdote or comment on their use of teamwork and project skills in their Senior Design and other university projects.

Additionally, participants shared that they gained personal self-awareness and self-management skills that enabled them to be a strong team player. Participants also shared that the course was helpful in thinking about and preparing for their career, including during interviews. Moreover, participants spontaneously acknowledged that they expect to need and be able to draw upon what they have learned in the EML once they begin their careers.

Limitations

There are several limitations to this study. First, this study was designed to be qualitative in nature with a small sample size. As such, findings cannot be generalizable. While a small sample size was expected, conducting this study at the start of the Spring semester was challenging, especially for most graduating seniors. Second, this study has a narrow scope using some of the specific learning outcomes in Senior Design. Our focus on Senior Design does not easily allow for exploration of learning regarding ethical decision-making, strategic thinking, finance, and some project management topics. Third, some students participated in focus groups with others from their team. This interaction might not be conducive to surfacing team problems.

Conclusion

The Whiting School's approach to engineering education not only exposes students to a variety of project-based learning opportunities, but also intentionally teaches them how to succeed at those opportunities to comprehensively address the ABET learning outcomes. In pursuit of this objective, the Engineering Management and Leadership course was developed to encompass competencies required for team success: diagnosing and solving team challenges, managing conflict, influencing others, and writing collaboratively. This study resulted in a

deeper understanding of student perceptions and experiences with some of EML's key learning outcomes – particularly, learnings immediately relevant to their undergraduate experiences.

Findings from this study can inform further evaluation such as pre- and post-course surveys, individual interviews, focus groups with faculty and capstone clients, and follow-up interviews with graduated students. An examination of skills and perceived benefits post-graduation would be helpful to understand which topics/content area may need different emphasis. Additionally, these findings can help inform the development of similar and complementary courses. For example, as a model for other universities to help undergraduate students acquire and develop interpersonal, professional, and non-technical skills required for early workplace success. Finally, future research should explore leadership and management curriculum and coursework across all U.S. engineering schools for continuous improvement and learning.

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Appendix 1. Focus Group Protocol

1. I've introduced myself so can we start with each of you sharing your name and one word that describes the course.
2. For my first question, please allow me to read to you this excerpt from the course description which is also in your handouts: "When engineers become working professionals, especially if they become team leads, managers, or entrepreneurs, they must juggle knowledge of and tasks associated with team citizenship and leadership, ethics, strategy, operations, finance, and projects. While engineers' success may depend on their own direct input – the sweat of their own brow – managers' success depends on their ability to enlist the active involvement of others: direct reports, other managers, other team members, other department employees, and those above them on the organizational chart. Sometimes even their suppliers or customers! You will learn these concepts and skills in this course. You will learn about teamwork and people management, and gain an introduction to strategy, finance, and project management. You will practice writing concise persuasive analyses and action plans and verbally defending your ideas… When you complete this course, you will be prepared to be a working professional."
3. Thinking about your experience in the Engineering Management & Leadership course, in what ways was the description achieved?
4. What did you learn during the course that made the most meaningful difference in the quality and performance of your Design or other Project team? Why? How?
5. Please state the first concepts, tools, or activities that come to mind, if any, when you think about how you used or applied the learning from this course while you were working on your senior design or other university project this fall.
6. Looking at the handout we've shared with learning outcomes, please share any (short) stories you have of times you have used each or ways in which you expect to use each:
    a. Diagnose team challenges and devise and implement solutions
    b. Coach your peers, team leader, client, or faculty
    c. Recognize and respond to conflict productively
    d. Influence others without authority
    e. Write collaboratively
    f. Use a project management technique such as design freeze planning, scheduling tools, customer needs assessment and conversion to product specs, team charters, change order management, etc.
7. In what ways, if any, did the course not support your design teams or projects that you wish it had?
8. Is there anything else that I should have asked or that you would like to share?