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Understanding the Development of Professional Skills in Extracurricular Engineering Project Teams

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Abstract

This Full Empirical Research Paper investigates how students develop professional skills on extracurricular engineering project teams. Previous literature acknowledges that professional skills are important for engineering students to learn before entering the workforce. However, many practicing engineers do not believe undergraduate engineering students are effectively learning these skills during their undergraduate education. In response, engineering programs have emphasized projects and experiential learning opportunities for students.

Previous research has identified extracurricular engineering project teams as one activity where engineering students develop professional skills, but it has yet to determine how students learn the skills in these spaces. By understanding the processes by which students learn professional skills on extracurricular project teams, instructors may be able to adapt or replicate the project team elements in their classes that promote the development of students' professional skills. To better understand how engineering students on project teams are learning professional skills, we are guided by the following research question: *What elements of project teams prompt engineering students to use professional skills?*

Four focus groups were conducted with engineering students participating in extracurricular project teams at their university. The focus groups followed two cycles inspired by Group Level Assessment: generating, appreciating, reflecting, and understanding. The first cycle focused on team structure and organization using activity systems from Activity Theory to illustrate key elements of the team. In the second cycle, guided by the Student Involvement Framework, students incorporated professional skills into their representations and discussed how these skills were learned and developed within their teams. Using thematic analysis, four elements of project teams were identified to be connected with students' perceived development of professional skills. Specifically, when students created reports, held leadership roles on their teams, collaborated with members of the professional engineering community, and worked on large, diverse teams they were prompted to use and develop a wide range of professional skills.

Introduction

Engineering curriculum teaches students the technical knowledge they will need for their career. Traditionally, engineering coursework consisted of solving close-ended problems from textbooks, deriving mathematical theories, and learning technical skills such as coding, soldering, and machining [1]. However, engineering work requires more than technical knowledge to be successful. Engineering work is more complex than typical well-structured textbook problems [2] and engineers spend most of their time doing socio-technical work rather than purely technical tasks, such as coding and simulations [3]. In this paper, professional skills, also referred to as transversal or generic competencies, are defined as cognitive, non-disciplinary skills that complement students' engineering work (i.e. communication, time management, etc.). Some of these skills are included in ABET criteria for engineering students such as communication and teamwork [4].

While professional skills are important for the engineering workforce, engineering students are often cited as lacking those skills at graduation [5], [6]. Recruiters for engineering jobs even look for students who have more than just technical knowledge when filling positions. Since many engineering undergraduates enter the workforce after graduation, they must learn these skills during their undergraduate careers. In response, academia has introduced professional skills into the classroom using interventions such as project-based learning. A literature review conducted by Boelt et al. showed that students believed project-based learning activities help develop various professional skills including communication, problem-solving, and teamwork [7]. Universities also offer opportunities for engineering students to participate in career-focused extracurricular activities that have been connected to professional skills.

In addition to classroom interventions, students believe they develop professional skills during co-curricular and extracurricular activities [8], [9]. Specific activities such as such as internships [10], [11], [12], service learning opportunities [13], [14], research experiences [15], [16], international experiences [17], [18], and project team competitions [19], [20], [21] are highlighted as spaces where students are learning and developing their professional skills throughout their undergraduate education. However, researchers have yet to identify how these environments are prompting the development of professional skills. While students have pointed to the fact that these activities give them opportunities to practice and develop these skills, literature has yet to identify which elements are prompting the practice.

We chose to investigate project teams because each team has a unique structure and rules so they offer a diverse set of elements that could potentially help develop students' professional skills. We define project teams as extracurricular activities where the goal is for students to design, build, and/or optimize products to complete a goal. Most project teams are based around competitions organized by engineering organizations such as the Society of Automotive Engineers (SAE) Baja and the American Society of Civil Engineers (ASCE) Concrete Canoe Competition. However, some project teams set their own goals rather than follow a competition structure. In addition to learning and applying technical engineering knowledge, students on project teams organize themselves into hierarchies and subteams, manage deadlines, collaborate with peers and professional engineers, and organize workflows. Previous research has shown that students on one specific project team developed professional skills [22]. However, general elements such as tools used, written requirements, and leadership roles vary from team to team.

Therefore, which aspects of project teams enable students to practice and develop professional skills is not yet understood.

Additionally, not all students can participate on project teams. In particular, lower socioeconomic status students have less time to be involved in extracurricular activities [23] and non-male students are less likely to be recruited to join project teams [24]. To combat this, while still gaining the benefits of project teams, some instructors have adapted project team competitions as projects in their classes [25], [26]. However, they may alter or remove the aspects that benefit students' professional skills development. For instance, project teams are organized by the students who elect what roles to perform, whereas professors may assign students to teams and roles. If the self-selection process is important for students to learn how to manage others or communicate their needs then instructors may be removing an experience where students could practice teamwork or self-direction. By determining which factors promote the development of professional skills, this research can help instructors more effectively integrate these skills into their coursework. Therefore, the research question guiding this study is: *What elements of project teams prompt engineering students to use professional skills?*

Methods

Over the course of two years, the primary author conducted four focus groups at two large, R1, predominantly and historically white universities we will refer to as University A and University B. Both universities sponsor and support multiple project teams. University A has more resources to support its many project teams, including multiple maker spaces for teams to utilize and a designated space for project teams to operate in, but also supports more teams that have to share those resources. University A also has multiple winning project teams that compete regionally and nationally. On the other hand, University B has fewer teams that are not as established and have not yet won many national competitions. It also provides less financial and building resources for student project teams.

The students were recruited directly through their project team via email or a class announcement. When selecting participants, we prioritized increasing the number of teams represented in each focus group. As such, only one student from each project team was invited to participate in each focus group from University A. If more than one student from a project team was interested in participating, one student was randomly selected to participate. At University B, where there are fewer teams and overall fewer students participating in project teams, all students interested in participating in the focus group were invited to participate.

All focus group participants were engineering students from a variety of engineering disciplines working on project teams at their respective universities. Thirteen students from eleven different project teams from University A participated in two focus groups. Nine students from four different project teams from University B were represented in the other two focus groups. Of the twenty-one students, seven identified as female. There was a female student in every focus group, but there was only one focus group where more than one woman participated.

The focus group protocol was based on Group-Level Assessment (GLA) [27]. GLA is a participatory focus group methodology from evaluation research. The method allows for a large number of participants in a focus group session and provides opportunities for written and verbal data to be collected. During a typical focus group, only participants who speak in front of the group are recorded which causes those with dissenting opinions, often marginalized individuals, to go unreported. Therefore, collecting individual and group data allows more students to be heard and represented in the data.

Each focus group was conducted in two rounds. The first round focused on the structure and organization of the project teams, while the second round discussed professional skills. Each round was composed of the generating, appreciating, reflecting, and understanding stages from GLA. During the first round of the focus group, students created a diagram of their project teams. To prompt students to think and write about various aspects of their project team, the diagram was designed based on Activity Theory's activity systems [28]. Activity systems consist of 6 categories to describe an organization: the tools used, goals of the group, how labor is divided, team rules, team members, and community members. After creating their diagrams, participants reviewed each other's diagrams, revised their diagrams, and then discussed their project team as a group. The second round of the focus group asked students to map professional skills onto the diagram of their project team. Participants wrote professional skills on their diagrams that were learned or used while working on their team. Examples of completed diagrams are included in Figure 1. To assist students, a list of professional skills from the Student Involvement Framework [29] was displayed during the second round of the focus group.

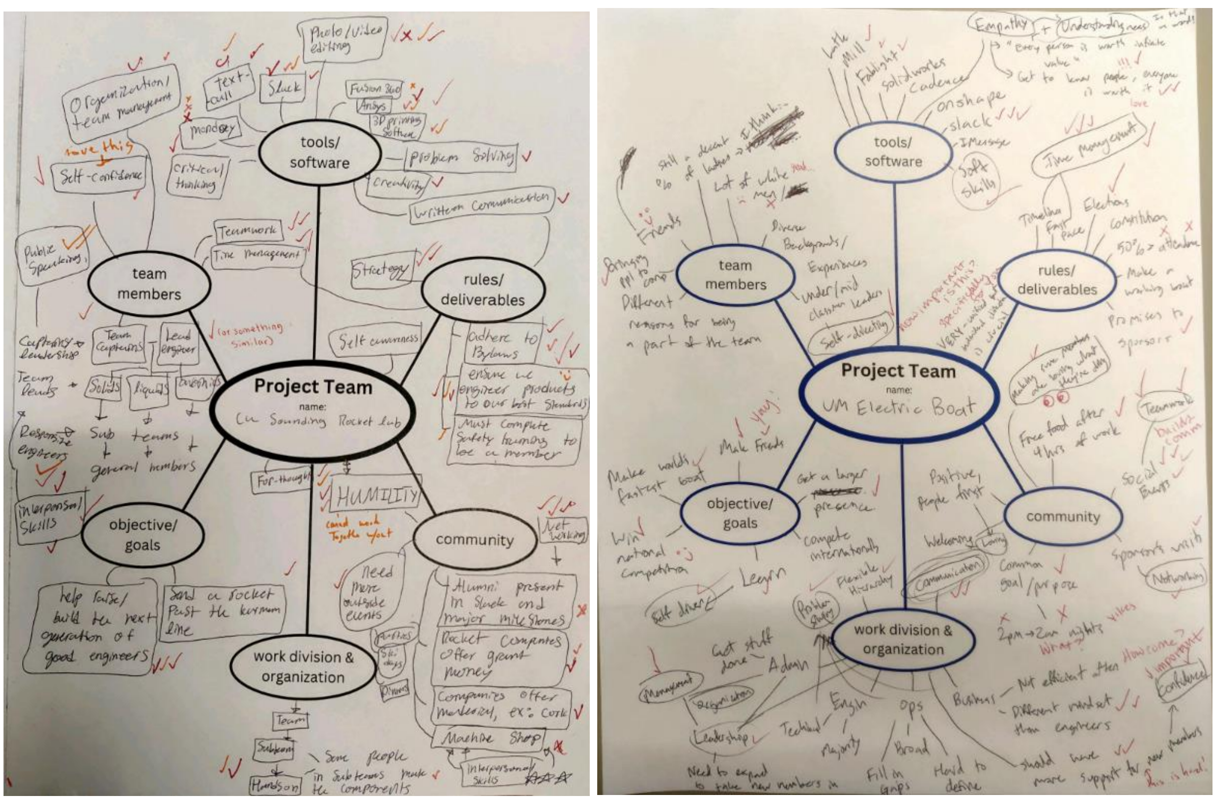

Figure 1. Completed Diagrams

The diagrams were initially coded based on Activity Theory to understand where students placed professional skills [30]. Then we used thematic analysis to identify what elements of their project team the participants had connected with practicing professional skills. After the second round, four elements of project teams emerged: creating reports, leadership opportunities, collaborating with the engineering community, and working on large diverse teams. Then we coded the focus group transcripts with these themes to triangulate the findings from the diagrams and understand more about these elements.

Limitations

While we recruited all active members of project teams, almost all participants were leaders on their respective project teams. Most led various sub-teams, and four were the highest-ranking officers of their project teams. This self-selection bias may have led students to talk more about the roles and responsibilities of leaders on project teams rather than discussing the outcomes for general members of project teams. However, when asked directly if general members also use professional skills, students said they did practice professional skills but were more focused on learning technical skills.

Participants were told there was no correct way to fill out their diagrams. This allowed students to describe their project teams and professional skills in a variety of ways but occasionally led to students filling out their diagrams in ways that were difficult to analyze. For instance, some students just wrote professional skills near the activity system where they used professional skills rather than in connection with specific elements. In preparation for this, the focus group protocol asked students to explain what they wrote on their diagrams in more detail and describe the elements that prompted students in different positions on project teams to develop and learn professional skills.

Also, some students did not share out loud with the larger group. Focus groups have the potential for only common perspectives to be voiced and recorded because students may feel pressure to echo dominant opinions. In particular, a participant who was the only woman in their focus group did not talk frequently or as much as the other focus group participants. We acknowledge that some students' experiences and perspectives may be different from the opinions that were recorded in the transcripts. However, we did allow students to create their diagrams first before sharing in the hopes that if there were major differences in the structure or skills used on their project team we could see the difference.

Results

According to students on project teams, making and presenting *reports*, having access to *leadership opportunities*, collaborating with the professional *engineering community*, and working on *large, diverse teams* prompted students to use professional skills. Each element was connected to multiple professional skills and showed up in various ways on the project teams. Table I shows the various skills that students connected to the element on their written diagrams.

Table I
Professional Skills Connected to Project Team Elements

Element	Professional Skills
Reports	Communication, Creativity, Problem Solving, Public Speaking, Strategy, Self-Direction, Teamwork, Written Communication
Leadership Opportunities	Communication, Interpersonal Communication, Leadership, Networking, Organizational Management, Public Speaking, Self-Confidence, Self-Direction, Strategy, Time Management
Engineering Community	Interpersonal Communication, Networking, Public Speaking, Teamwork
Large Diverse Teams	Cross-Cultural Skills, Global Awareness, Interpersonal Communication, Problem Solving, Teamwork

Reports
Creating reports was one of the most common elements and appeared on almost every diagram, and project team members routinely connected creating reports to professional skills. During the focus groups, students discussed written reports such as required safety and mathematical reports for their competition, internal documents that students created for transferring knowledge to future team members, and design reports for sponsors or alumni. They also discussed presenting reports in design reviews to team members and external alumni or sponsors. Students connected multiple professional skills with creating reports including communication, public speaking, strategy, and teamwork.

Participants described how writing formal reports required by their competition provided opportunities to practice technical communication skills. On the other hand, creating internal written documentation gave members opportunities to practice less formal written communication methods and contributed more to their teamwork skills. Presenting to sponsors, alumni, or peers was an opportunity to practice public speaking skills while presenting to sponsors was connected to using strategy.

Leadership Opportunities
Every project team had a hierarchical structure that varied depending on the number of members on the team and how many sub-groups the team was organized into. All teams also held some kind of election to choose their own leaders. One participant noted how project teams are unique spaces to develop leadership skills saying, “I put [leadership] as like one of the skills that you would learn just because like in the classroom setting you don't have very many opportunities to step up as a leader. But in a project team, if you want to have more responsibilities there's always something you can do.”

More broadly, leaders in project teams have opportunities to practice a wide range of professional skills. As one student put it, “once you [like] have the technical knowledge and you're in the leadership positions, then you have, you're exposed to a lot more of the management side of things where [professional skills] would come up.” Participants connected leadership positions with various professional skills including self-confidence, interpersonal communication, organizational management, written communication, public speaking, leadership, networking, and self-direction. Leadership opportunities were connected with different skills depending on the responsibilities of the leaders on a specific project team. Participants mentioned responsibilities such as leading meetings, presenting design reviews to sponsors and/or alumni, organizing workflows, managing deadlines, and overseeing documentation required for travel, safety, and competitions.

When asked if students in leadership positions were chosen because they could already perform professional skills, most students disagreed. Rather, they believed that leadership opportunities provided experiences for students to practice professional skills. One student, Louis, explained how leaders practice the skills in their positions stating, “Yeah, I think it's really hard to teach [professional] skills…And it's- it's kind of like more of a practice thing. And so, as people kind of fill the leadership shoes, they get better at this kind of stuff.” On project teams, students are organized into smaller sub-team groups that focus on one specific element of the overall design such as suspension, aerodynamics, or avionics. In future years, a student can be elected as the leader of their sub-team, then to a higher, more general position such as chief engineer, treasurer, or chief safety officer. The scaffolded approach allows students to practice professional skills in different ways and at varying degrees.

Engineering Community

Project teams interface with the engineering community frequently as part of their work. Participants wrote down and discussed groups such as engineering alumni from their institutions, external manufacturers and testing facilities, faculty members from their institutions, and sponsors as members of the professional engineering community that they work with.

Most often, working with the engineering community was connected with practicing networking. Students mentioned securing internships through external project team partners, networking with alumni who were previously members of the same project team, and meeting faculty members as examples of networking through their project teams. One student described how their project team had regular opportunities to network with industry professionals saying, “I mean, we have a lot of networking. We have general meetings, and then sometimes we have special general meetings where alumni come through, and they kind of talk to us and they, you know, look at our progress and talk to us about the industry and things like that.”

Students also mentioned how working with engineers in industry allowed them to use other skills such as public speaking, creativity, and teamwork. Project teams that offered more formal events such as alumni and sponsor design review presentations connected working with the engineering community with these other professional skills.

Large Diverse Teams

The last element connected to using professional skills was that students on project teams work on large, diverse teams. Students mentioned they work on project teams with students from different grade levels, majors, and countries. Project teams are primarily composed of engineering students, but all teams work with students from multiple engineering majors and often from non-engineering majors regardless of the product. One student from a rocketry project team said, “We are like primarily aerospace engineering, but we still have like a good number of [mechanical engineers], [computer scientists], [computer engineers], [electrical engineers], couple of oddballs out there from like physics or like naval architecture." Other teams mentioned working alongside business and art students. One student discussed the importance of working with non-engineering students saying, "We got a really skilled person from [the business school] and he came in and developed our whole business team. And, um- he actually like wrote an op-ed advocating for getting more [business] people into these project teams and is like connecting the college of engineering with [the business college]." Other than major, students mentioned how every team has "a bunch or people with different, different personalities and different ways of thinking and we're all like working together, improving our technical skills to, you know, at the end to do the engineering stuff we have to do."

Working on a large, diverse team led to disagreements and cultural literacy issues. These conflicts gave students on project teams opportunities to practice professional skills such as interpersonal communication, problem-solving, global awareness, cross-cultural skills, and teamwork. On multiple diagrams, students connected conflict resolution to interpersonal communication, teamwork, and problem-solving skills. One student mentioned that "when we're working with a big group of people not everyone is gonna agree. So problem solving I think fits in with teamwork and coming up with that solution together." Meanwhile, cross-cultural, communication, global awareness, and teamwork were connected to working with students from different countries. One student described how "our team has, like we have Russian, we have Turkish people, we have someone from Saudi Arabia, we have Indians so like on one hand is like just for the work side you have to learn how to communicate." They went on to describe how working across cultures was necessary for their team to complete their work and prompted students to use professional skills like cross-cultural communication and teamwork.

While students described their teams as diverse in terms of nationality, personality, and age, they did acknowledge that project teams are male-dominated. In alignment with previous literature about project teams, a female participant noted that, "our team has gotten like an increasingly worse, like gender dynamic…there's a really common thread where the guys who join the team have the confidence to kind of like fake it until they make it and then the girls get very self-conscious about the fact that they don't know how to do things and then they tend to like stop coming." Another male participant remarked that there were almost no women on his team.

Discussion

The elements of project teams were connected with multiple professional skills. Except for networking, which was connected exclusively to collaborating with the professional engineering community, almost every skill was associated with numerous elements of project teams. Therefore, students on project teams use professional skills in a variety of ways because they are prompted by multiple elements to use those skills. For example, teamwork was written in connection to numerous elements of project teams and was even written multiple times on the same diagram. Some students discussed how working on large teams required them to practice teamwork, others believed working on presentations and written documentation prompted them to use teamwork, and a few thought working with professionals prompted more teamwork skills.

Also, all of the elements of project teams that prompted students to use professional skills were connected to a sense of responsibility. Rather than classwork, where students have little to no choice in taking the course or working on the project, project teams are spaces where students are intrinsically motivated to work on them. As one student stated, “I think, like in my experience you can get by kind of like you don't need to be good at these to like just go through college. I think the project teams offer a unique experience where members have like the motivation and are given the responsibility to actually develop [professional skills]. And that's what gives them, like, the rapid learning and growth to get to where they need to be.” The responsibility that students on project teams have over their work increases the effort that they put into the projects and therefore increases their potential for developing outcomes like professional skills. One student echoed this idea when they described how leaders on project teams may be developing more professional skills than general members because “they're also some of the most invested members so I feel like it makes sense that they would be getting the most out of something that they put the most time into.”

Some project team elements that students discussed are not unique to extracurricular project teams, but they are also not common in engineering curriculum. During the focus groups, students mentioned there are few opportunities to be a leader in the classroom. Without those leadership positions, students may not get opportunities to resolve conflicts between peers, organize workloads for a team, set deadlines for projects, or make design decisions during their undergraduate education. A study by Polmear et al. highlighted how leadership opportunities in extracurricular settings were also important to get students to understand what kinds of skills they need to work in engineering [31]. On one diagram, a student even wrote that they had no management experience in their engineering classes, and other students agreed. Similarly, engineering coursework does not frequently require students to work on interdisciplinary or large teams. Students on project teams routinely work with students who are not in their courses or majors. On multiple diagrams, students wrote about learning how to work and communicate with everyone on the team. In addition, during the focus groups, students discussed how they often have to work with students they did not agree with or even got along with. In courses, students often have the luxury of choosing who they work with. However, students on project teams have to learn how to navigate and work on teams where they do not pick their colleagues. Students must get experiences where they can develop their professional skills during their undergraduate education because they need to be able to use them after graduation. Not all students have the opportunity to experience industry before accepting a job, so designing experiences where they can practice and develop professional skills is vital to their success in the workforce.

Conclusion

Project teams are unique organizations that offer students environments to increase their technical and professional competencies. Overall, students believed creating reports for their products, having leadership opportunities, interfacing with engineering professionals, and working on large, diverse teams prompted students to use professional skills on their extracurricular project teams. Specifically, students believed writing and presenting reports are opportunities to work together and utilize their written and verbal communication skills. Meanwhile, project teams offer plenty of leadership roles where students can practice professional skills such as public speaking and self-confidence. Working with professionals provides opportunities for students to network and use teamwork skills with engineering industry. Lastly, tension is common when teams are composed of various individuals with different personalities from different backgrounds. On project teams, students are responsible for handling conflict that arises where students can practice skills such as cross-cultural and interpersonal communication to keep the work on track. Project teams contain a wealth of examples where students can practice and develop a myriad of professional skills in a variety of ways.

While not all instructors have the time, resources, or motivation to incorporate all elements of project teams into their classes, consider altering one element to create instances where students need to use professional skills. For example, instructors who have implemented or are interested in implementing project-based learning activities should consider incorporating these elements so students can experience aspects of project teams that prompt students to use professional skills. For instance, consider allowing students to handle disagreements amongst themselves before offering solutions so they can practice managing conflicts or design projects where an entire class has to organize and manage the workload so students have to work with all students in the class and manage each other. Instructors could also organize opportunities for students to work with the broader engineering community by presenting projects to alumni or reaching out to companies to create and/or discuss their projects.

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