Women Leading Engineering Environmental Challenges at a National Contest

Dr. Hilda Cecilia Contreras Aguirre, New Mexico State University

Hilda Cecilia Contreras Aguirre received an Ed.D. degree in Higher Education Leadership from Texas A&M University-Corpus Christi (TAMU-CC), and an M.Sc. from the University of Technology of Compiègne, France. She is now a researcher at New Mexico State University (NMSU). She focuses her research on qualitative studies addressing minority and underrepresented student college persistence, such as Latinas' performance in STEM, mentoring, and Latinx' research involvement in Engineering. She is also interested in participating in collaborative efforts promoting interdisciplinary research. Lastly, she is currently the PI and Director of the Research-Oriented Learning Experience (ROLE) in Engineering, a National Science Foundation-funded project, and the coordinator of a Latinx Femtoring/Mentoring program at NMSU.

Dr. Ginger Scarbrough, WERC Environmental Design Contest, New Mexico State University

Visiting Assoc. Professor, CHME focusing on Materials Engineering and serving as Program Manager of the WERC Environmental Design Contest, both in the College of Engineering, New Mexico State University.

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Abstract

The technological innovations, environmental challenges, and current job demands call for better addressing the gaps and limitations of engineering students. This study focused on engineering students participating in an environmental national contest housed at New Mexico State University. With a mixed-methods approach, 20 student leaders completed surveys and participated in focus groups. Researchers used the path-goal and transformational leadership theories as well as the hill model for team leadership and the leadership labyrinth model to inform the threads and strategies adopted by student leaders to accomplish their projects. The data analysis revealed that student leaders used communication, decision-making, vision, and passion to lead their teams. In particular, there were differences between women and men leaders when it came to leading others; while men leaders used a relaxed and fun way to lead, women adopted a more serious and rigorous approach in their leadership roles. Furthermore, women leaders found it more difficult to lead their peers and still have a positive relationship with them, and continue their friendship. Overall, women leaders took advantage of their leadership role in increasing their sense of belonging to engineering, acquiring technical skills, and expanding their knowledge of what the engineering profession can look like. Women leaders also reported having further developed their teamwork and leadership skills. Lastly, the multiple benefits that engineering students reported on leadership development by participating in these types of projects could help change the current engineering curricula, benefiting students in their role as future professionals.

Background

The first hint of an engineering contest dates to the 19th century when the Army Corps of Engineers improved inland river navigation by considering suggestions from the public [1]. Later, in 1932, the Accreditation Board of Engineering and Technology (ABET) was created to oversee the education, accreditation, regulation, and professional development of engineering professionals and students in the United States [2]. With the creation of ABET, post-secondary institutions increased their interest in including design in engineering programs focusing on environmental, health, safety, ethical, social, and political topics [3]. Commonly, by working on their capstone projects, senior engineering students apply the requirements of engineering design projects. There are different engineering design types, approaches, and scopes. The one explored in this study is through an engineering environmental national contest. The design contest described in this study distinguishes itself by offering five new environmental design challenges each year that require teams to build a working bench-scale demonstration. At least one task is offered for each engineering discipline, highlighting that all engineers can engage in sustainability efforts.

The environmental design contest of this study is housed at New Mexico State University and represents an opportunity for underrepresented groups from across the country to improve their confidence, skills, and sense of belonging in STEM fields, in particular engineering. Participating teams solve real-world environmental challenges that the world faces, with topics addressing environmental and climate justice concerns. Over the past five years, demographics have consistently shown women to dominate contest participation. On average, 53% of participants have been women – a significantly higher percentage than the 25.5% of women enrolled in U.S. engineering programs in Fall 2022 [4]. Hispanics have averaged 17% participation, as compared with an average U.S. Fall 2022 enrollment of 15.8% [4]. In addition, an average of 20% of the participants reported being first-generation college students, as compared with approximately 10% of all U.S. engineering students identifying as first-generation [5]. These statistics indicate greater participation in an engineering program than expected from enrollment data. Of, perhaps, even greater interest is that of the 20 team leaders participating in the 2024 contest, 15 identified as women. The implications for women in engineering leadership positions are further explored in this work.

Commonly, undergraduate engineering design contests tend to address a single engineering discipline, offer the same design challenge each year, and require only a report and an oral presentation [6], [7]. A multidisciplinary, innovative, and hands-on demonstration would better simulate real situations that students will face once they join the workforce [8]. In addition, there has been a noticeable increase in the active participation of women students as leaders of the teams [8]; therefore, this study aims to gain insight into engineering students' leadership as they participate in a team-based design challenge. The research question framing this study examined: What traits of leadership did women engineering students implement throughout their participation in the national environmental design contest?

Contest Characteristics

The contest has been held annually each Spring semester since 1991. Organizers, in coordination with industry and government agencies, propose different environmental design challenges, and student teams choose one to work on, usually, in a semester. The focus of the projects is on environmental and societal real-world problems. The following are some examples of student projects: Microplastics Quantification in Reservoirs, Rural Wastewater Treatment for Water Reuse, Long-term Water Storage, and Dust Removal for Space Suits [8]. From the beginning, one of the contest requirements is to select a team leader. Teams were composed of six to ten freshmen to senior students, sometimes even including graduate students, and from a variety of engineering majors. Students were leading mixed teams composed of both boys and girls. With the help of one or a few faculty members from the students' home institutions, in most cases as part of the student capstone projects, students agreed to participate. Participants register, attend short courses, and write progress and technical reports. To be able to come up with a successful design, teams face technical and non-technical factors [9]. Therefore, teams are supported by three different engineering professionals: 1) a faculty advisor from their home

institution who performs a consultant role, 2) a group of judges, assigned by the contest organizers, who provide feedback, and 3) professionals with expertise in economics, health and safety, and legal aspects who audit student projects. The interaction with this set of professionals greatly contributes to students' workforce development and increases their confidence to communicate their ideas effectively [8]. Most teams spend two semesters at their home institution developing initial engineering designs, building working prototypes, and iterating their designs based on these models. The contest happens in three days, where teams present flash pitches, oral and poster presentations, and bench-scale demonstrations. This is the only time when all teams are together and can engage with each other. On average, 12 institutions participate in the contest, bringing over 20 teams.

Literature Review

There are several benefits for students who participate in design contests, including team motivation, commitment to the project, and awareness of teamwork dynamics [3]. In a broader sense, engineering design contests provide students with real societal problems and the possibility to propose solutions, improve their interpersonal skills, and interact with professionals [3]. When students participate in design contests, due to the nature of the project and the need to communicate with different stakeholders (e.g., faculty and professionals from industry and government), students enhance their communication skills and become more aware of economic, environmental, and design challenges [3], [10]. Also, participants need to develop critical thinking, quantitative reasoning, problem-solving, and ethical understanding to accomplish their project [10].

In prior years, participants of the environmental engineering contest reported an increased sense of belonging in engineering and improved abilities to communicate their ideas, present their research, and establish professional relationships [8]. In addition, most participants agreed that their involvement in the contest allowed them to acquire and apply new knowledge as needed, an essential skill to develop for a dynamic and constantly evolving workforce [8]. Additionally, Swam and colleagues [9] pointed out that participation in the environmental contest was a fulfilling and challenging experience for students. A valuable learning from the project and the contest was the need to think outside of the box [9]. Team leaders learned and gained skills in people and time management, such abilities were useful for their projects and even after college [9]. Other leadership traits were the use of relational leadership to accomplish the team goals. The adoption of a collectivistic leadership would allow a student leader to pursue a shared vision through a process-oriented approach exhibiting a more mature level of leadership [11].

Also, Scarbrough [8] reported women as the most common leaders among the contest teams. According to the Continuous Improvement through Data, Evaluation, and Research (CIDER) [12], in 2022, women in engineering represented 24.5% of the total enrollment. Despite being a minority group in engineering, women who persist in engineering programs tend to take leadership roles [13]. Also, once enrolled in engineering, women persist as shown by their

graduation rates, accounting for 25.5% of all who complete engineering degrees [12]. There are also differences in women's enrollment by engineering discipline. Harandi and colleagues [14] pointed out that women tend to enroll more in biomedical and environmental engineering due to the relation of these disciplines with social issues and climate change. Most prior research focuses on the overall learning of contest participants after taking part in the contest. This study addresses the key role of engineering women students in leading their teams, their leadership approach, and some differences in leadership perceptions between team members and team leaders.

Theoretical Frameworks

Multiple leadership theories could describe the type of leadership adopted by women student leaders in the environmental design contest. However, due to the college learning environment and the goal of the project to develop skills to propose solutions for real-world problems, the path-goal and transformational leadership theories contribute to understanding women leaders' approach to leadership. In addition, based on the study's findings, both theories contributed to a better understanding of the leadership used and adopted by team leaders in this particular cohort.

On the one hand, the path-goal theory focuses on how leaders motivate followers to enhance performance and satisfaction. A typical behavior of a leader is showing participative leadership where communication and decision-making are essential aspects [15], [16]. On the other hand, transformational leadership theory is applied when leaders engage their followers in such a way that they feel satisfied with their work and performance. Leaders can elevate higher levels of followers' motivation and self-actualization [15].

To complement the path-goal and transformational leadership theories, two models visualize specific applications of women leaders, highlighting their approaches and challenges in leading their teams successfully. First, the hill model for team leadership developed by Zaccaro and colleagues [17] emphasized horizontal leadership in which both leaders and the team work together to achieve team effectiveness. The leader monitors the team and decides what actions would ensure the team accomplishes its goals. Also important is the leader's attention to internal and external situations to solve problems and propose solutions [18]. To achieve team effectiveness, it is critical to focus on performance, the team's work outcomes and its quality and development, and the ability of the team to keep working together for a particular goal [19]. Second, the leadership labyrinth model developed by Eagly and Carli [20] highlights the multiple difficulties women face to be leaders in a society still highly dominated by male leaders [20]. The labyrinth metaphor simulates the hardship experienced by women to reach high-level leadership positions and Hackman and Johnson [15] identified the following barriers: 1) deny women knowledge in important business functions; 2) lack of mentoring and performance-based feedback; 3) family responsibilities; 4) concerns of empowered women; 5) exclusion of women from (male) networks; 6) discrimination; 7) isolation; and 8) stereotyping. In turn, Rosener [21] pointed out differences between men and women to lead, highlighting better interpersonal skills

and empowerment in women leaders. In addition, other differences include women being more often social leaders and leading small groups, using a participative and democratic leadership style, tending to collaborate more, and engaging in transformational leadership focusing on follower needs [22]. The theories and models adopted were incorporated after researchers performed the data analysis and found appropriate frameworks for this study. Furthermore, through the chosen theories and models, researchers highlight the importance that leadership has for teamwork in achieving goals and, in particular, the leadership challenges women face in male-dominated fields such as engineering.

Methods

This study used a mixed-methods approach, collecting qualitative and quantitative data [23]. The evaluation and research team developed a post-contest survey to collect quantitative and qualitative data. In addition, three focus groups were conducted with each team's student leader. In total, 20 student leaders participated in the study, five men and 15 women. All student leaders responded to the surveys and participated in the focus groups. The Institutional Review Board (IRB) approved this study.

Data Collection

The research team conducted the focus groups on the first day of the contest in April 2024, due to students following a more structured schedule during the contest's first day. Students were invited to participate beforehand and signed in to participate in one of the three focus groups. The three focus groups happened during the morning, and each one lasted approximately one hour. When students got to the room assigned for the focus groups, they first read and signed a consent form and then completed the survey. Next, the researchers used a focus group protocol that included questions to guide the conversation. The questions were related to leaders' perspectives, leadership traits, learning outcomes, and recommendations. Team student leaders were participative and willing to share their experiences. The discussion of the focus groups was audio-recorded with the permission of participants. Concerning the survey, the first set of questions asked students about the impact of participation in the environmental design contest's key areas. Students were asked to rate on a 5-point Likert scale ranging from 1: Strongly Agree to 5: Strongly Disagree. The key areas were divided into two sections, the first section included questions on self-efficacy associated with problem-solving and design skills, as well as communication and presentation skills. The second section addressed topics about teamwork and leadership. Furthermore, the survey included five open-ended questions concerning learning outcomes, recommended changes, and graduate school interest. Lastly, the survey also collected participants' demographic information.

Data Analysis

The information collected from the survey's open-ended questions and focus groups was analyzed. For the audio from the focus groups, the researchers obtained the transcripts. With the assistance of Dedoose, a software to analyze qualitative data, the researchers started with the

identification of units of information. Next, those data units were classified into themes and categories using comparative techniques [24], particularly highlighting women students' leadership traits. Individually, two researchers performed two rounds of coding, one that organized the overall information collected and the second coding included an analysis focused on leadership and teamwork. At two different timeframes, researchers met and discussed the units identified and agreed on topics that informed both rounds of coding. Quantitative results were analyzed through descriptive statistics and assessment of normal distribution to highlight statistical significance among the survey statements. The data were not normally distributed, and researchers performed a Mann-Whitney U analysis to determine whether students' scores for each statement differed among men and women leaders. Qualitative and Quantitative data were collected and analyzed at the same time and concurrently.

Findings

Qualitative Findings

This section is mainly composed of the data collected through the focus groups and some other information reported in the surveys through the open-ended questions. Student participants of the environmental contest who took the role of leaders underscored challenges, approaches, and strategies to lead their teams. The following themes explain the main leadership traits adopted by women and men leaders:

Communication

As the first trait of leadership, communication was key for all activities performed even before starting work on the environmental design contest. The next students' quotes show how important communication was for all team members and how the leaders used this strategy to make sure all members were involved and doing each activity needed for the project.

> *I've noticed with communication a lot of times that you just need to be patient kind of goes hand in hand because as a team leader…you kind of got to make sure you set a good timeline, but also it's realistic. (MAN-FG1)*

> *As a team leader, it was a lot of coordinating and just making sure that things were in line, planes were set, and we were good to actually go, but everybody was involved in every part of everything. (MAN-FG2)*

> *I think communication is definitely the biggest one, especially with teams of three to seven people. You need everybody to know what's going on, be on the same page, and know what their tasks are. (WOMAN-FG1)*

> *Just have to repeat things a lot to make sure people are staying on top of it and then just*

communicating and obviously leading by example by doing your stuff as well. Super important. (WOMAN-FG1)

I think heading with communication was a big thing. Figuring out what needed to get done and who was working on what parts and what was completed. (WOMAN-FG2)

Through these quotes, students reflected on the critical role of leaders in maintaining effective communication. Two men leaders commented on their experiences in communicating with team members. These two quotes seem to have a more passive tone compared to women's experiences in making sure communication was effective, on time, and understandable. The environmental design project has different phases and deliverables, and this creates even more of a need to monitor and delegate activities among team members.

Decision Making

Decision-making, as the second leadership trait identified, underscores leaders' role in deciding the best approach to lead their teams. While there was a student leader who decided to take more control of the decisions, other student leaders shared more of the responsibilities among team members, even considering asset-based approaches, highlighting team members' skills and knowledge that could contribute to the project. In particular, men leaders adopted a more relaxed and fun focus when it comes to working with a team.

I would say we, for the most part, shared a lot of the responsibilities. I don't think I was, I don't know, I feel like we shared the burden almost. (WOMAN-FG1)

I just think being decisive is important. Making an informed decision and then sticking with it instead of going back and forth and then everyone's confused by what you're actually doing. (WOMAN-FG2)

Maintaining a lighthearted attitude so everybody else kind of feels more comfortable. I feel like that was kind of maybe more my role that was just trying to be chill and make everybody else relax. (MAN-FG3)

I would say confidence in just making it fun was really important for our group. We had lots of very long hours in the lab and just playing music and hanging out while doing experiments made people want to continue working on the project (MAN-FG2)

Decision-making is important in every step of the environmental design project, and without it, the project could not be done. Team leaders were aware of making informed decisions at some critical moments of the projects and helped the team move forward to accomplish the team's goals.

Vision

As the third trait, vision helps student leaders to make sure team members know what they need to accomplish, with the information, resources, and time frame available. The student quotes included in this theme point out student leaders' recognition of their human resources, team characteristics, and paths to follow to make sure their project goals were achieved.

> *It was very difficult to facilitate colleague versus friend, so definitely trying to understand that mindset. I think that was my biggest learning curve through this project. (WOMAN-FG1)*

> *You have to be flexible. We learned a lot of flexibility in our testing and we had a lot of things go wrong...Keeping the team together be like, it's okay, we're working on it. We're moving along, figured out. (WOMAN-FG1)*

> *I think it just took me a while as a leader to find what their strengths were and have them do that rather than be mad at them for not being able to do what we're asking of them. (WOMAN-FG1)*

> *It was definitely a large team to lead, but it actually was very kind of inspiring to have so many people want to work together and I didn't really feel at any point there was a hierarchy. We were kind of just all together. (MAN-FG2)*

> *In our group, we kind of just worked on everything together. We were all in the lab just communicating at one time if one person had a question we'd just say it out loud and one person would answer. (WOMAN-FG2)*

> *Most of the team leader was a lot of coordinating and just making sure that things were in line, planes were set, that we were good to actually go, but everybody was involved in every part of everything. (MAN-FG2)*

Student leaders were able to get to know team members well and inspire others to work to achieve a goal. By communicating a vision, women and men leaders could accomplish that team members contribute to the project, commit to the tasks, and are enthusiastic about their learning outcomes and project results.

Passion

Passion, as the fourth leadership trait, shows student leaders' motivation and joyfulness in participating in these types of projects, where students are exposed to real-world social problems. Mostly women leaders were convinced about the importance of environmental design projects to improve, in some cases, the life quality of disadvantaged communities.

I did really enjoy that part of it and we got to make several site visits and reach out to community organizations and just talk to people and see what they thought about and what their complaints were, and I think it opens your eyes as an engineer. (WOMAN-FG1)

We chose a neighboring small, disadvantaged community near our school where my grandma actually grew up, so I had a big personal connection to it…connecting with the community and incorporating, benefiting the environment obviously and looking into different ways…be creative and think sustainably. (WOMAN-FG1)

This project specifically really aligned with my personal interest. I'm interested in water resources through the stormwater task and then of course environmental. (WOMAN-FG1)

Student leaders were grateful for the opportunity to participate in a meaningful environmental research project. For a couple of students, this was the second time they were participating in the environmental design contest and a few of them mentioned that they had such a great experience that they would participate again.

Quantitative Findings

The survey collected data concerning student participation in the environmental design contest. The first section included questions on self-efficacy associated with problem-solving and design skills, as well as communication and presentation skills. A summary of survey results, see Table 1, shows women and men leaders' differences in their responses through medians and standard deviations in the following statements:

Table 1. Differences between women and men leaders in participation impact

Impact	**Women Leaders**		**Men Leaders**	
	Median	SD	Median	SD
My sense of belonging in engineering has increased	4	**0. 7888106**	4	0.5477226
My confidence in solving environmental problems has increased.	4	0. 5163978	4	0.5477226
I can acquire and apply new knowledge as needed, using appropriate learning strategies.	5	**0. 4830459**	5	0.4472136
My communication and presentation skills have improved.	4.5	0.8232726	4	0.8366600

I feel more comfortable designing and using an apparatus.	5	0.5163978	4	0.7071068
I was motivated by the environmental justice aspect of our team's task.	5	0.7071068	4	0.8366600
I feel more prepared to work as a professional engineer.	5	**0.8432740**	4	0.5477226
The Flash Talks helped me understand the marketing of engineering designs.	4	1.224745	4	0.7071068
The Flash Talks helped me learn to communicate with a non-technical audience.	4	1.0327956	4	1.2247449
I can solve complex engineering problems.	4.5	0.5270463	4	0.5477226

Overall, the calculation of median ($\bar{X}$) and standard deviation (SD) for both groups show for women leaders: $\bar{X}1 = 5$ and SD = 1.224745, and for men leaders $\bar{X}2 = 4$ and SD = 0.7010197. In terms of student impact after their involvement in the contest, women leaders scored higher than men leaders. The second section addressed topics about teamwork and leadership. Table 2 illustrates differences found in women and men leaders after participating in the environmental design contest.

Table 2. Differences between women and men leaders in leadership and teamwork

Leadership and Teamwork	**Women Leaders**		**Men Leaders**	
	Median	SD	Median	SD
The problem we solved is relevant for society.	5	0.3162278	4	0.5477226
My interest in working with a team increased.	4	**1.0327956**	4	0.8366600
My teamwork skills increased.	4.5	**0.6992059**	4	0.5477226
My leadership skills increased.	5	**0.6749486**	5	0.4472136
My ability to effectively work with a team to overcome obstacles increased.	5	**0.7071068**	4	0.5477226

In general, for the second section of the survey, the calculation of means ($\bar{X}$) and standard deviation (SD) for both groups shows that for women leaders, $\bar{X}1 = 5$ and SD = 0.787919, and for men leaders, $\bar{X}2 = 4$ and SD = 0.637742. These results showed increased women leaders' confidence in the technical aspects of their projects, and improved confidence in their abilities as engineers and leaders in terms of working with others and the development of their own skills. The SD values bolded highlight women leaders ranking higher in such statements compared to

men leaders. To demonstrate statistical significance, the researchers performed a Mann-Whitney U test, finding no significant difference between men and women leaders. The tests may show low significance due to the small sample sizes, however, the collected data shows positive trends towards increased women's leadership.

Discussion

This study's goal was to gain insight into engineering students' leadership as they participated in a team-based design challenge. The research question investigated: What traits of leadership did women engineering students implement compared to men engineering students throughout their participation in the national environmental design contest? Overall, women leaders showed multiple leadership traits throughout the process and the different stages of their projects. The decision to become the leader varied among participants, both women and men, and while some student leaders were appointed by their team members, other student leaders were convinced that they wanted to lead their teams. The themes included in the qualitative findings section help understand women's approach to leadership, observing differences with men leaders. Such themes highlight challenges, difficulties, and conflicts faced throughout the execution of the projects, but also motivations, dynamics, and strategies adopted to accomplish the team's goals. The first two themes, *Communication and Decision-Making,* informed women leaders' intention to make clear the expectations among team members and follow up on activities and tasks. In comparison, men leaders seemed to take a more laid-back approach using words such as patience, comfort, and fun. Also, most women leaders decided to take advantage of team members' skills and strengths to address different project tasks such as doing the mathematics, conducting the research, and writing the report. As stated by Swam and colleagues [9], an important learning outcome of contest participants is to be able to think differently, adjusting and changing approaches as needed.

Furthermore, women leaders integrated a highly participative approach among team members, and for the most part, women leaders made collective decisions; that is, all team members had a say in the decisions made. This leadership approach can be found in the path-goal theory, where leaders motivate others through participation in decision-making [15], [16]. Particularly, the hill model for team leadership spotlights team effectiveness as a result of working together, showing cohesiveness and commitment to deliver quality in the work performed [18], [19]. In the following two themes, *Vision and Passion,* both men and women leaders reflected on the importance of the projects, highlighting the important role and commitment of their team members. Women leaders were aware of the human and capital resources they had to accomplish their projects; they understood their limitations and valued the contribution of others. Such women leaders' approach aligned with Hackman and Johnson's [15] examples of transformational leaders who not only achieve that their followers engage in their assigned tasks but also feel satisfaction with their contributions. In turn, male leaders emphasized the overall functioning of their teams without pointing out specific areas, activities, or strategies. In addition, women leaders were more vocal than men leaders in expressing that they fully

enjoyed the social and environmental approach of the projects. Women leaders found the projects meaningful and with a real sense of leveraging efforts to support minority and disadvantaged communities.

Additionally, the survey results showed women leaders' higher ranking in several statements compared to men leaders, particularly in the leadership and teamwork aspect. Without a doubt, women leaders both gained and reinforced their leadership skills while leading their teams and became aware of the challenges leaders face in motivating and inspiring others to make things happen. In turn, men leaders did not provide detailed information about the dynamics of their teams and were more focused on the project tasks. For women leaders, it was particularly challenging was lead their fellow peers and keep their friendships despite discussing and solving issues related to the project. This study found several leadership traits and behaviors adopted by women leaders throughout the environmental design contest aligning with Rosener [21] and Eagly and colleagues' [22] research. Authors in [21] and [22] pointed out how women are usually better equipped for inviting collaboration, participation, and engagement. Also important is to be mindful of followers' needs and motivation, so they achieve higher levels of self-realization, which women tend to address better than men.

Implications for Practice

The following implications for practice include recommendations that institutional agents could incorporate to improve engineering students' education and achieve a more holistic educational approach. Based on the findings of this study and the literature reviewed, these implications can leverage institutional efforts to better prepare students in gaining leadership skills for the current job market:

- Institutions should incorporate courses on relational leadership skills into the formal engineering curriculum to improve the overall performance of both the team leader and the team members.
- Engineering programs should include more project-oriented activities, in which students face complex projects and challenging work dynamics similar to the workplace.
- Advisors should be able to detect the level of leadership of team leaders to build upon those skills. The goal would be to develop students' leadership identity at higher levels.
- Professors should be aware that leadership is a skill that students can develop over time, and their time in college should be used to improve such skills. Formative assessment should incorporate leadership aspects for students to practice as part of the activities performed in a class.

Future Work

The continued interest in improving engineering students' education through real-world and workplace-like experiences should be a priority for institutions. The multiple benefits that prior research and this study's findings presented on leadership development should inform and transform current engineering curricula to adopt needed changes that can benefit students in their

role as professionals. An innovative and holistic approach is needed to better prepare students for the workforce. One important aspect for future work is to focus on the development of a leadership identity among engineering students that should be reinforced throughout their academic preparation. In particular, women as a minority group in engineering could benefit from developing such important skills that would eventually help them persist in college and later as future professionals in the engineering field.

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