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Building a Leadership Toolkit: Underrepresented Students' Development of Leadership-Enabling Competencies through a Summer Research Experience for Undergraduates (REU) in Engineering Education

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Abstract

The development of inclusive leaders is essential for the success of future engineering and our nation. Equipping students with vital leadership-enabling competencies is necessary to develop a workforce that is prepared to act ethically, and responsibly, and tackle unforeseen challenges in the future. Inclusive leaders, or leaders that are self-aware, empathetic, and prioritize diversity, equity, and inclusion in their decision-making, are essential for the forward progress of engineering. A growing body of literature highlights the numerous ways in which students may develop leadership skills outside of the classroom through involvement in out-of-class activities (e.g., internships, clubs, sports, and research experiences). Research Experiences for Undergraduates (REUs) may provide students with a unique opportunity to develop leadership-enabling competencies that will prepare them for leadership in graduate school, the engineering industry, or academia.

The goal of this research was to identify how students' engagement in an engineering education virtual REU site contributed to their development of essential leadership-enabling competencies. The research question guiding this study was 'What inclusive leadership-enabling competencies and skills did engineering students learn and develop during an engineering education Summer REU program?' Qualitative data was collected via weekly open-ended surveys from 9 students (7 women, 2 men) participating in an REU over 9 weeks. Participants in this study consisted of students from underrepresented groups in engineering (e.g., Black, Latinx, women, students from low SES backgrounds, or first-generation students), attending large public research universities across the United States. This study implemented mixed methods to understand what leadership competencies were occurring most frequently and how students were learning and developing these competencies. A combination of text mining for frequency (quantitative analysis) and deductive and inductive coding (qualitative analysis) was used to analyze the data. A codebook was developed based on the leadership-coupled professional competencies that engineering industry leaders identified as essential for engineers entering the workforce. Researchers also allowed for other competencies and leadership-enabling skills to emerge from the data.

Findings from this work indicate that students were developing a vast amount of inclusive leadership knowledge and skills from participating in the virtual REU site. This paper highlights, through the use of word clouds and text mining software, the many leadership-enabling competencies that participants developed throughout the summer research experience (e.g., learning, communication, adaptability, self-awareness, balance, networking, etc.). Further, students were able to develop digital literacy, increased communication skills, knowledge of career pathways, intrapersonal growth, and interpersonal relations. This work offers a novel contribution to the literature in understanding how students can develop technical engineering and research skills as well as professional and leadership skills in the same space. Findings from this work help to illuminate the benefits of this virtual REU site focused on engineering

education research resulting in terms of developing inclusive leadership skills. Implications for future REU programs, students interested in developing leadership skills, engineering graduate programs, academia, and industry employers are outlined.

Introduction

For decades the National Science Foundation (NSF) has funded Research Experiences for Undergraduates (REU) to engage more students in the advancement of research. An REU site typically hosts a small cohort of students for a summer and focuses student research on a certain topic or theme [1]. In 2021, multiple institutions and faculty members in engineering education collaborated to host a virtual REU entitled, Establishing New Generations of scholars to Amplify and Grow Engineering Education (ENGagED). The REU's purpose was to engage more underrepresented students, specifically, Black and Latinx students, and as a result of intersectionality, women, people from low socioeconomic status (SES) backgrounds, and first-generation individuals among other minoritized identities in engineering education research. Engineering education is a relatively new field of research compared to other fields in science and engineering (e.g., chemistry, physics, and civil engineering). The REU ENGagEd site was intentionally designed around four main goals: 1) provide an engaging experience for underrepresented students in engineering education; 2) equip students with vital research, engineering, and leadership skills; 3) provide undergraduates a diverse network of faculty and graduate student mentors; and 4) broaden participation in engineering education and amplify the voices of underrepresented students.

The calls for increasing and improving leadership in engineering education have been echoed throughout industry, academia, and policymakers across the nation. ABET accreditation has expanded to require more leadership and professional development throughout undergraduate programs in engineering. The 2022-2023 ABET accreditation criteria for engineering encompasses a need for students to develop technical skills (e.g., basic principles of engineering, science, and mathematics; analyzing and interpreting data; and drawing conclusions based on data) while simultaneously developing professional and leadership skills (e.g., planning tasks, establishing goals, teamwork, cultivating inclusive environments, leading a team, ethics, responsibility, critical thinking, and thinking about the big picture in terms of economic, environmental, social and global impacts) [2]. There is an increasing demand from the engineering industry and employers for engineers entering the workforce to be equipped with high levels of leadership and professional skills [3]–[5]. Historically, leadership and professional skills have been referred to as "soft skills" indicating lesser importance than the "hard" or technical skills typically associated with engineering. Leadership development was often pushed to the margins of engineering education using an end-of-program project or a few elective courses to fulfill the requirements [6], [7]. However, recent work explores the potential and success of integrating leadership and professional development into the technical aspects of engineering education. This literature indicates that out-of-class activities such as summer internships or research experiences (e.g., REU programs) can be beneficial in furthering the development of leadership skills during a student's engineering education [8]–[10]. This study explores the leadership-enabling skills and competencies, or the leadership "toolkit", that students in the REU ENGagEd site were able to develop throughout the experience.

Background

Leadership in Engineering

Over the past few decades, calls from NSF, ABET accreditation, industry leaders, and scholars have noted the demand for leadership-enabling competencies to be embedded into undergraduate engineering programs [2], [11]–[13]. Leadership has largely remained undefined in engineering programs. Using responses from civil engineering and construction executives, a recent study defined leadership as a set of technical and professional knowledge, skills, and attributes that can be developed to enable leadership in students [5]. Data from this same study indicated the most desired leadership-enabling competencies in graduating engineering students were: communication skills, professionalism, critical thinking/problem-solving, self-awareness, ambition/drive, time management, management, ethics/responsibility, big-picture thinking, humility, teamwork/collaboration/networking, quality control, adaptability, computer skills, safety/risk management, assertiveness, people focus, legal knowledge, and economic principles and trends [5]. While leadership-enabling competencies may vary by discipline, there is a pressing need across all engineering industries for more graduating engineers to be prepared with strong inter- and intrapersonal skills when entering the workforce in addition to their industry-specific technical knowledge [4], [14], [15].

Current engineering industries have an ever-growing demand for more diverse, inclusive, and ethical leadership. Unfortunately, engineering continues to be an industry that lacks diversity, equity, and inclusion in leadership positions. Many people of identities including Black, Latinx, women, low SES backgrounds, LGBTQ, and disabled are largely underrepresented in engineering majors and even more so in the engineering workforce and leadership positions [16]–[18]. There are a wealth of benefits associated with diversity in the workplace, including an increase in profits, improvements in customer relations, innovation, and problem-solving [19]–[21].

Inclusive leaders are essential for the forward progress of engineering. Inclusive leadership involves equipping students with leadership skills such as self-awareness, empathy, and decision-making skills informed by diversity, equity, and inclusion. A 2020 article from the Harvard Business Review outlined that inclusive leaders share six common characteristics: humility, visible commitment, awareness of bias, curiosity about others, cultural intelligence, and effective collaboration [22]. Inclusive leadership is broadly defined in this paper as leading a diverse group of people in a way that respects all ideas and includes the voices and opinions of all; It allows individuals to feel valued for their contributions and aims to reduce bias and employ empathy and understanding for all [20], [22]–[24]. There remains a lack of literature on how to develop inclusive leadership skills in engineering education programs.

Leadership Development through REU Sites

Prior research on the topic of leadership development in engineering education has largely focused on the development of leadership through out-of-class activities (e.g., clubs, internships, organizations, part-time jobs, conferences, and research). Out-of-class activities provide students with an opportunity to apply technical knowledge while simultaneously developing professional skills [9], [25], [26]. Prior work has analyzed the outcomes of undergraduate research experiences on students' development of critical leadership skills [8], [10], [27]. West and colleagues found an REU was able to help students develop skills directly related to the

engineering of 2020 [10]. Their work further highlighted a need for engineering students to learn technical skills in societal and professional contexts and practice interacting with people from different demographic backgrounds [10]. Prior research on undergraduate research experiences highlights the impact of these experiences on diversity, equity, and inclusion in science education by providing students from underrepresented groups with opportunities for professional development and job attainment [29]. Undergraduate research experiences allow students from diverse backgrounds to develop skills such as critical thinking, writing, and communication skills that are vital to successful careers in science and engineering [29].

Student participation in REU programs was impacted by the COVID-19 pandemic and raised concerns related to REU learning outcomes. Several REU programs over the past few years were held remotely or virtually due to the COVID-19 pandemic. Research on the impacts of virtual or remote REU programs is limited. One study by Nyarko and colleagues highlighted how, despite challenges encountered during a virtual REU, students demonstrated gains in knowledge, confidence, and communication skills [30]. Even as many REUs return to in-person experiences, research into the impacts of virtual or remote REUSs can be useful as developers and hosts of REUs and other undergraduate experiences consider the advantages and disadvantages of in-person, hybrid, remote, and virtual formats.

The REU ENGagEd Site

The ENGagED REU focused on cultivating an awareness of and exposure to research in engineering education while broadening participation in engineering and providing students with professional and technical skills that could be translated to engineering academia and industry. The REU was modeled to intentionally expose students to a variety of engineering leadership-enabling competencies and allow them to learn and develop these skills throughout their summer research experience. Students were able to move through the levels of Bloom's Taxonomy from remember to higher levels of understanding, applying, and analyzing [31] during the REU. The following program components were used to develop students' technical and professional leadership-enabling competencies: virtual setting, research projects, posters, technical workshops, journal club, faculty seminar networks, community hours, and weekly reflection and survey.

A Virtual Setting

Due to restrictions following COVID, the REU site was held virtually. While this meant some students and faculty never actually met face-to-face, it allowed students the opportunity to work on projects across various geographic regions and meet and connect with faculty and mentors around the world. This virtual site was strategically organized to optimize student engagement and learning opportunities in a remote environment. The REU faculty and mentors prepared for months before the summer, reviewing the literature, attending training, and holding meetings to provide the most engaging setting possible through a virtual site. The virtual REU offered students frequent interaction with mentors, peers, and faculty via Zoom meetings, Zoom working sessions or "power hours", and virtual social events (e.g., cooking class, game nights, and open conversations).

Research Projects and Posters

When applying to the REU, students were able to select a research project from a variety of project descriptions that collaborating labs in the REU were currently working on. Based on their interests and selections, students were then paired with a faculty member and a graduate student mentor for the duration of the summer. The first author of this paper served as a graduate student mentor for the program and the second author was a faculty mentor. All faculty members and graduate students attended training on mentorship of underrepresented students in engineering and learned how to best mentor and support undergraduate researchers before the start of the program. Students were then assigned various tasks for their research projects throughout the summer including but not limited to, completing IRB training and protocols; reviewing literature; collecting data via surveys, interviews, or text mining from Twitter/social media posts; analyzing data; developing graphics for disseminating data; writing literature reviews, findings sections of articles, and positionality statements; discussing project findings with their mentors and research team; sharing project findings with their peers; collaborating with other undergraduate and graduate researchers, faculty members, and preparing final deliverables such as individual research posters and reports.

Each student worked on a specific project of their choosing as a part of on of the REU site's faculty member's labs (located across various institutions). Some of the research topics included, exploring the experiences of women in STEM, Black students in engineering, and community college engineering students. Students were guided by initial literature and research questions on their selected topic but were given the freedom to explore and present their findings using a variety of methods and innovative strategies. Training in both quantitative and qualitative methods provided initial exposure to a variety of research methods in the first two weeks of the program. Some students analyzed qualitative interviews or quantitative survey responses while others used text mining of Twitter posts or a literature review as their main source of data analysis. Each of the student's unique inquiries and projects were presented in the final poster symposium at the end of the REU. Students were supported by their mentor and research lab throughout the summer and presented their own unique findings in the poster symposium to the larger REU group. The final posters creatively portrayed each of the student's projects and findings of their work throughout the summer.

Technical Workshops

Technical workshops were developed and led by experts in the subject matter. A two-day workshop was held on quantitative research and a three-day workshop was held on qualitative research that featured Dr. Johnny Saldaña. During the workshops, students attended virtual lectures and engaged in various activities, such as working in small groups on projects and assignments. Students were given resources such as research-related books and access to workshop recordings.

Journal Club

Students were assigned various journal articles to read in engineering education. They met twice weekly with faculty members and authors of the various works for "journal club" sessions. Students led the conversation with faculty members and authors and brought questions or comments they had on that day's reading to the session.

Faculty Seminar Networks

Students also engaged in weekly meetings with different leading faculty members in engineering education. Faculty discussed a variety of topics including socio-political influences on engineering, data interpretation, doing diversity equity, and inclusion work, engineering and education policy, and humanitarian engineering. Students were able to discuss these topics freely with faculty and ask questions.

Community Hour

Twice a week students met with faculty members and spent time discussing various topics and questions they had on their research projects. These discussions were informal and allowed students opportunities to discuss questions and interests they had as they related to their research projects or future careers. Topics discussed at these meetings included but were not limited to, facilitating work-life balance, entrepreneurship for engineering, managing money, and career paths, setting boundaries, juggling various tasks, and mental health.

Weekly Reflections and Surveys

At the end of each week, students reflected on what they had learned. All nine students completed an open-ended survey for nine of the ten weeks of the REU. Students were able to write as little or as much as they would like. Some of the weekly reflection prompts included:

- Write a brief reflection on what you learned and accomplished during the week. The entries can include something you found interesting, surprising, or challenging.
- Describe something valuable you learned, such as a skill you developed this week through both the cohort programming and your individual project.
- Describe what you learned this week specifically about engineering education research and from what person and/or activity?
- What have you learned about yourself this week from participating in the REU? Please link each learning outcome you describe to the person(s) and/or activities that helped you learn each.
- How have your activities this week helped you address your research question?
- Write any questions you have or ideas you want to explore further."
- Has anything you've learned this week shifted the focus or aims of your project? How?

Research Question:

To add to the body of knowledge and more deeply understand how undergraduate engineering students develop essential leadership-enabling competencies this study explored what students in engineering gained as a result of participating in this virtual REU experience. This study was guided by the following research question:

What inclusive leadership-enabling competencies and skills did engineering students learn and develop during an engineering education summer REU program?

Methods

This mixed-methods exploratory research sought to understand the outcomes of an REU in terms of leadership development. The first and second authors participated in the REU as graduate and faculty mentors. Qualitative data was collected from the weekly surveys and reflections throughout the REU. The quantitative analysis consisted of initial text mining of the survey data to understand the frequency of each leadership skill students were self-reporting throughout their open-ended survey responses. Text mining of the surveys was conducted in Excel to understand what competencies the participants reflected on most frequently. This was done using the leadership competency framework [5] by searching for the following competencies and their synonyms: communication skills, professionalism, critical thinking/problem-solving, self-awareness, ambition/drive, time management, management, ethics/responsibility, big-picture thinking, humility, teamwork/collaboration/networking, quality control, adaptability, computer skills, safety/risk management, assertiveness, people focus, legal knowledge, and economic principles and trends. The qualitative analysis consisted of coding and thematic analysis of all the written survey responses and artifacts from the REU. The survey responses were analyzed in addition to artifacts including the REU materials and provided literature, final project posters, workshops, books, and seminars. The surveys were analyzed both deductively and inductively by exploring other emergent leadership-enabling competencies the students mentioned. Emergent codes such as research-related skills, reading scientific literature, and multitasking were also developed and used in text mining to capture competencies identified as important by the students but not included in the leadership competency framework. The first and third authors memoed the participant responses as recommended by Birks et al. [32]. The researchers met weekly to discuss findings and used cutting and sorting to develop themes in response to the research question.

Findings

The leadership toolkit was developed using initial quantitative analysis of the data to understand the frequency in which students were self-reporting what skills they developed throughout the REU. Text mining of student survey data informed the development of a leadership toolkit shown in **Figure 1**. After developing codes for various leadership-enabling competencies, text mining was used to understand the most frequently mentioned competencies in the student survey data. The frequency of occurrence is indicated by the size of the text of each leadership-enabling competency in Fig. 1. Some of the lesser-mentioned competencies (e.g., economic principles and trends) have been enhanced to increase readability in the figure. Some of the most frequently mentioned competencies were communication, research, networking, and problem-solving. Skills such as patience and economic principles and trends were mentioned less frequently (i.e., one or two times) in the survey data.

Figure 1 Leadership Toolkit: Inclusive leadership-enabling competencies that were most frequently mentioned in the data

The leadership and professional competencies model in **Figure 2** presents the findings of the qualitative analysis of the open-ended survey data. The qualitative thematic analysis resulted in five themes that describe how students developed as inclusive leaders by participating in this research experience. Under each inclusive leadership competency is a description of the skills that students reported developed through this research experience. The bolded bullet points represent the leadership-enabling competencies that employers in the construction industry identify as crucial factors when hiring a new employee [5]. Under these bolded points is a list of other competencies that students identify as crucial leadership and professional skills that would help them in their future careers. Each of the themes is presented and explained in depth.

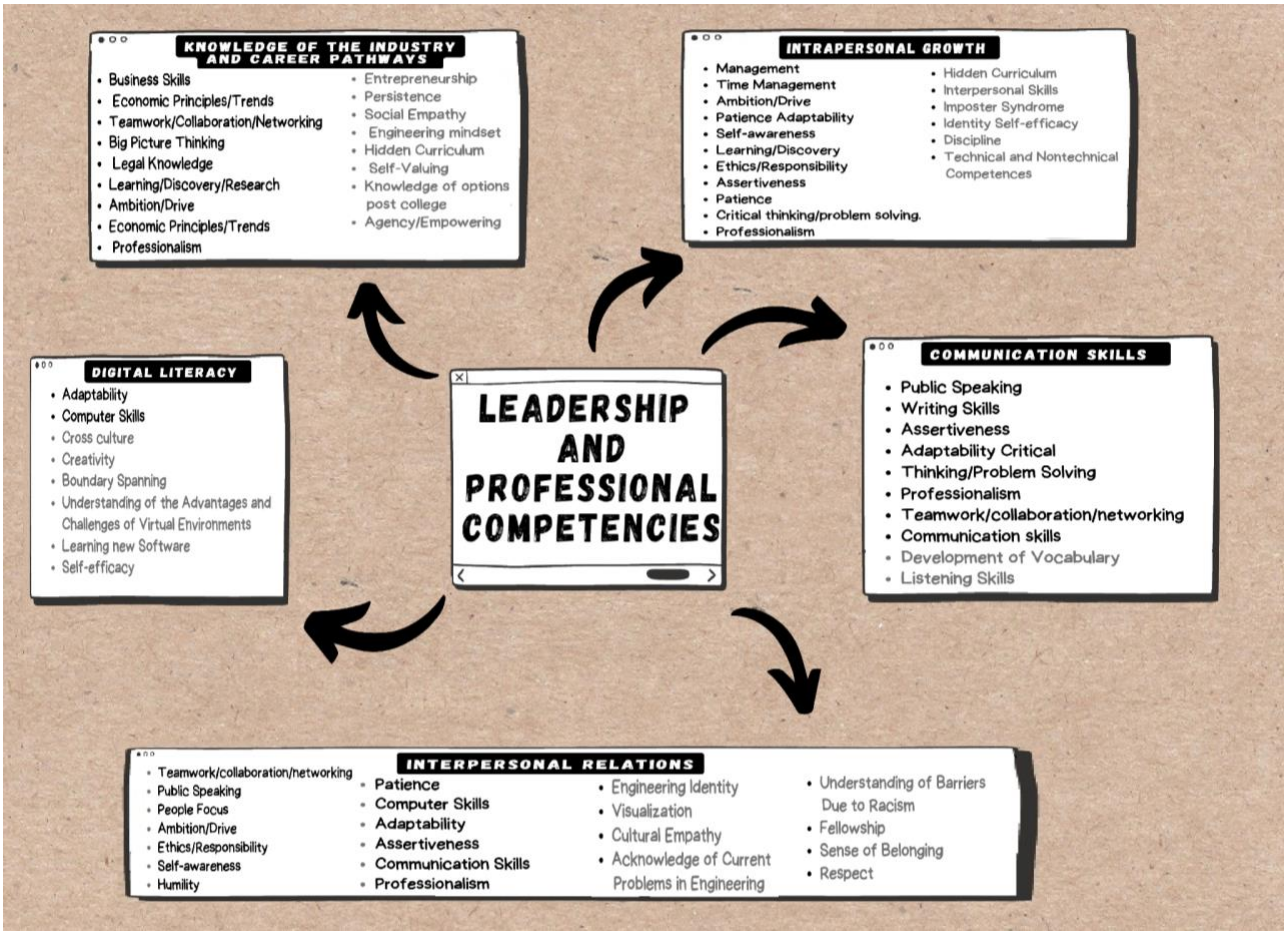

Figure 2 Conceptual Map of Themes from the Data: leadership and professional competencies

Students reflected on developing essential inclusive leadership skills through this program. Participants expressed a greater interest in politics, environment, and research in engineering education as possible career paths after participating in this REU. Among other areas, students also demonstrated considerable interest in social justice and social empathy. These future engineers also reflected on gaining skills such as big-picture thinking, legal knowledge, and environmental concern. Survey responses indicated that having meaningful discussions with current engineering leaders, researchers, and graduate students was a crucial tool for considering their career paths. Specifically, students from underrepresented groups related the knowledge obtained from interpersonal relations with engineers from underrepresented groups with a stronger self-efficacy in their academic formation and a stronger desire to become role models for other minorities. Hence, activities outside the classroom, such as this REU, are an essential tool for developing skills that employers are looking for, in addition to providing a better understanding of the career paths in engineering. These experiences influence how students perceive their future impact on society as engineers and encourage undergraduates to persist in their career path. Thus, this lifelong learning creates agency, empowerment, and upward mobility in minority groups.

Knowledge of the Industry and Career Pathways:

ENGagED REU participants reflected that exposure to this experience boosted their understanding of post-college options by raising questions about what they could do with their major and encouraging them to investigate other areas where they could work and study after graduation. Students expressed that being involved in engineering education research contributed to their engineering mindset and helped them visualize future careers in industry or research. In the following quote, a student shared how the REU experiences strengthened their connection to the field of engineering:

> I would say that this week I learned more about my interests. I was reaffirmed about my curiosity, and my decision to pursue engineering and continue to study it in college.

Other students expressed a positive change in perspective on research and engineering and an intention to persist in engineering programs and fields. The following quote from a student illustrates how involvement in a program with multiple interactive activities such as social activities, one-on-one meetings, journal clubs, and guest speakers, helped change their perspective on research.

> There were great activities that changed my perspective of the REU as an inclusive and inviting experience for all the participants, ridding me of the idea that the research experience was a cold, straightforward experience.

As is evident from this response and similar answers from other students, some students had existing negative perceptions of research as a "cold" experience and hesitations around research in engineering as a possible career path. However, this REU experience provided students the opportunity to engage in an exciting way with a new field of engineering research, engineering education. This encouraged many students to contemplate this area of research in their reflections and widen their knowledge around potential career pathways with an engineering degree. Thus, these experiences not only helped ameliorate learning, discovery, and research skills but also provided a better understanding of future career pathways and the options they have.

Students indicated that speaking with engineering entrepreneurs provided them with more knowledge of and confidence in the industry. Students from underrepresented groups and first-generation students in engineering may have had fewer opportunities to discuss compensation and negotiating strategies. However, students reflected on learning how to ask for their worth and discuss these important leadership and career strategies in their surveys. One student shared,

> This week's Q&A session with engineers who are also entrepreneurs. I was able to hear how our speakers have dealt with not knowing how to confidently name their prices. I feel that as people of color, it is a challenge for us to assign our worth via the services we provide. It made me feel included.

This student reflects on feeling included and gaining useful knowledge about knowing your worth as a result of this interaction with professional engineers and entrepreneurs. Most undergraduate students and professionals in the field feel that this topic cannot be discussed with

other engineering community members due to a fear of breaking unspoken social norms. Underrepresented groups often feel that asking the wrong type of question, such as inquiring about salary, is taboo, which can prevent them from upward mobility. Therefore, many students enter the industry with little knowledge about valuing themselves as engineers and negotiating salaries. This REU sought to expose underrepresented engineering students to leaders in the industry with shared identities and backgrounds which ultimately provided them with the tools to bolster their knowledge of possible career paths and skills to navigate the engineering industry.

Interpersonal Relations:

Students reflected on developing skills such as communication, cultural empathy, collaboration, networking, respect, as well a sense of belonging in the REU community. This REU offered students opportunities to feel a deep sense of belonging and form a community amongst people of shared identities in engineering. One student shared,

> The sense of community was a strange feeling compared to most of my experiences I recall during my engineering education, and I feel like it should be an environment that most students should experience [a sense of community] in their academic journey.

This sense of community fostered an experience where students who are largely underrepresented in traditional engineering settings felt more represented and included in this REU. This environment allowed them a safe space to practice and develop interpersonal skills. For example, students reflected on developing "effective communication" and "public speaking" skills throughout their time in the REU. One student reflected on developing the skill of active listening through their project experience where they had to conduct qualitative research interviews. They shared,

> Building rapport [in qualitative interviews] is applicable to my leadership skills in student organization life, as well as workplace professionalism in my current role as a peer mentor/coach to high school seniors transitioning to their post-secondary paths and to current college students. Plus, it extends to any future job since collaboration is inevitable. Also, the active listening and communication skills [were helpful because] one has to apply and make sure the other person has the opportunity to speak and share their full thoughts and know that I am listening and that what they are saying matters.

This student reflected that the process of building rapport and communicating and collaborating in their process helped them to develop interpersonal skills. For example, active listening was identified as useful to them in their current position as a mentor to high school students as well as in their future careers, acknowledging that "collaboration is inevitable". This student is not only portraying an understanding of the skill but that they were able to practice it and even begin to consider how they will apply it to their current and future roles.

Students also reflected on developing interpersonal skills such as teamwork/collaboration and conflict resolution. In an activity during a workshop, students were asked to form small groups in Zoom breakout rooms. They were instructed to each share their research interests in engineering education and implement active listening while their peers were speaking. The groups then had

to find a way to combine the two interests into one project that addressed all the research questions and goals that the team members were interested in finding solutions for. One participant shared,

> My group had the challenge of two seemingly very distinct ideas to support engineering education and students. Yet, we brainstormed and found solutions to make it one project that would cover both our original RQ and the goals for students addressed.

While the student noted it was challenging to combine two very different ideas, they were able to collaborate and come to a solution that met the criteria of the exercise.

Digital Literacy, Global Teamwork, and Boundary Spanning:

The virtual delivery method in which this research experience was conducted brought to the attention of students the advantages and disadvantages that online environments bring to the industry. However, it also provided students with a unique opportunity to gain skills associated with digital literacy, global teamwork, and boundary spanning, including computer skills, working with people with different backgrounds and identities in different time zones over different modalities, adaptability, fostering inclusion and community online, and creativity. After COVID-19, the accelerated increase in the use of technology as an alternative solution to continue performing normal activities and the increase in globalization in the engineering industry has generated a need for employees to improve their computer and adaptability skills. The implementation of this online approach provided students the opportunity to boundary span by collaborating with people across multiple locations, disciplines, and cultures. Students were exposed to new online tools and software in this REU. One student shared,

> I learned a lot about how to present with a partner over Zoom. While I have done many presentations before and even a couple of poster presentations, I had never done a poster presentation online. While it was a little stressful, I think it turned out well and I had a great time.

While the virtual format of this REU offered students a unique opportunity to develop remote working and collaboration skills, it added challenges and the opportunity to manage those challenges. One student reflected,

> A skill I continued to develop this week was time management and self-care balancing. The time differences we all were working on led to me having early session times and I had to get my sleep schedule set to work with my commitments while still taking care of myself and trying to get enough sleep and have breakfast before the session so that I wouldn't be distracted or in a negative mood while I worked with others virtually. This was important because the sessions were long even with a break in between. It was exhausting for me to participate since I had to have my camera on at all times or like 99% of the time.

While these challenges are common for remote work and can lead to exhaustion or burnout, it is important to develop coping skills of time management, balance, and self-care. Students also found unique solutions by implementing their strategies to build community and create inclusion

and motivation in a virtual space. Some students collaborated to organize virtual accountability sessions. One student described their accountability sessions as,

> Accountability sessions were where a group of us get together [over Zoom] for three hours at a time to work on our projects. We discuss what we want to accomplish for each hour and work diligently to meet each goal. I have found these sessions to be very helpful as they mimic the in-person study sessions that I am so used to. While I would complete my work whether I had the sessions or not, I find them to be more enjoyable than working completely by myself.

Communication Skills:

The development of communication skills was a recurrent theme throughout the student surveys. The students reported developing an awareness of stereotype threat and imposter syndrome and developing more confidence in their communication skills throughout the REU. One student shared,

> So from participating in the REU, I realized that I feel pressure and nervousness despite learning that it may be a thing stemming from aspects like the imposter syndrome which is more prominent in people from marginalized communities or oppressed groups in an environment where they feel like an outsider of sorts. Like it is something that I am aware of and know that it may just be something in my head, but I limit myself from speaking or participating in discussions.

Another student shared, "I have internalized this 'speak when spoken to' behavior that I grew up with. It is great that I can let go of that and communicate with others in a valuable way." This student recognized that they have internalized cultural norms such as only 'speak when spoken to' which may have limited their participation in the past. Students in this study also indicated that they were able to develop networking skills, arrange and lead difficult conversations, and foster positive relationships with mentors and role models. One student shared,

> I've learned that I am capable of positive interaction with mentors and those I look up to. I am not very talkative, so sometimes I find it difficult to reach out and uphold extended conversations unless I prepare a lot beforehand. This week, I pushed myself and had 2 meetings which showed me that when I reach out, I can foster connections and have positive educational conversations …. I have been sharing my findings to my family and friends.

This response is a clear example of how positive interaction with engineering members can bolster undergraduate students' confidence. It is crucial to validate the importance of sharing new ideas and encourage students to learn how to communicate their topics of interest properly, as this could lead to the expansion of knowledge, development of leadership, and the possibility of new research involvement.

Students also found the REU useful for developing unique professional communication skills. They were able to practice their listening, emotional intelligence, adaptability, critical thinking/problem-solving, public speaking, writing, and professionalism skills. One student shared,

> I learned that I need to expand my vocabulary... a lot. During this week's journal club, I realized I had 7 terms from the papers that [professor] assigned. I need to read more intentionally, and really try to learn the vocabulary, because I'm certain at least one of the terms was one that stumped me in previous weeks. As well, hearing some of my peers speak, I think I could try to be more concise with my thoughts.

Here, this student recognized a need to expand their vocabulary and focus on communicating concisely in the future. These are skills they picked up through reading the scientific literature and listening to researchers, mentors, and peers. Other students reflected on developing specific skills related to communication through the REU such as communicating with bias-free language, communicating expectations, and analyzing people's body language. This exemplifies the specific communication skills that the students were able to learn and develop that contribute towards inclusive and emotionally intelligent leadership.

Intrapersonal growth:

Analysis of the survey data suggested students developed several intrapersonal skills (e.g., self-awareness, adaptability, ethics/responsibility, management, assertiveness, and learning/discovery) throughout the REU program. Individuals in this study created healthy habits to be able to manage their time wisely and accomplish their tasks. Students practiced things such as setting a timer for smaller tasks to assure time was being allocated properly. Others shared how they had to decide at times to ask for help when they needed it. One student reflected, "I impressed myself this week with my ability to consume knowledge." Another student shared that they learned a lot about "ethics with scientific studies [...] I think it is valuable to have this information to do my research and make sure anything I am a part of is ethical."

Many students began to consider issues of justice, diversity, equity, and inclusion as they relate to engineering contexts. Through the REU activities, assignments, and conversations, students were able to reflect on their own identities and backgrounds and develop more cultural empathy, self-awareness, and inclusive leadership skills.
One student reflected,

> It's awful to admit it, but I grew up in an extremely racist and unaccepting household. As a young child, racist ideals were planted in me, and I had little understanding of any of the implications of being a minority in a way I did not personally experience. As I have grown up and escaped the environment, I have done a lot of learning and personal growth in educating myself about issues such as systemic racism. I am so grateful for this opportunity to learn more and become more conscientious and aware of my privilege and how to be an ally to those around me.

This student expressed gratitude for this experience for exposing them to new knowledge and ways of thinking. After working in a space where they created a sense of community, they were able to gain an awareness of additional barriers that people of different identities may face due to systemic racism. This awareness of the individual's privilege as well as the inequities that exist in many engineering institutions is essential for inclusive leadership development. Students seemed to generally appreciate the REU for providing a space for discussions of justice, diversity, equity, and inclusion to occur. Another student shared,

> I found the discussion to be very cathartic because we were able to talk about legitimate issues that the engineering field faces that are not typically humored in the classroom. While we were unable to fully round out the topic due to a lack of time, I was still grateful for the opportunity to discuss issues like these with my peers in engineering as opposed to individuals in the humanities who understand and recognize many of the societal problems we talked about, but not necessarily as it related to engineering and engineering education.

Another form of intrapersonal growth that was found in this data was increased self-compassion. Students in this REU site were underrepresented in their engineering programs and institutions. The participants frequently reflected in their surveys the need they felt to work harder to prove themselves, the fear of speaking up or having imposter syndrome in their respective fields. Through the literature and discussions around inclusion in engineering, many of the students were able to develop a stronger engineering identity and skill set that bolstered their confidence to succeed in the field. This allowed some students to find increased self-compassion as well. One student shared,

> I learned that I need to be a little kinder to myself in the aspect of not applying so much pressure to myself for being a first-generation college student in engineering. While I may not have had resources growing up, I have them now and I am capable of graduating as an engineer just like my classmates regardless of backgrounds.

This concept of self-compassion can be used to improve self-image and resilience and overcome perceived inadequacy by treating oneself with kindness and acknowledging elements of shared humanity [33]. Fostering self-compassion is essential to intrapersonal growth and inclusive leadership skills. Self-compassion should be encouraged for engineering students, particularly for those of underrepresented backgrounds, to promote a healthier, happier, and more productive engineering environment.

Discussion

Engineering is a profession that requires a vast amount of technical, math, and science knowledge. Consequently, there is little space left in the curriculum for courses that specifically focus on leadership and professional development. Prior literature calls for a stronger focus on developing leadership skills throughout engineering education [6]. However, there exists little knowledge of how leadership or professional skills can successfully be integrated into technical engineering classes. Out-of-class activities, such as research experiences and REUs seem to have success in integrating both professional and technical learning outcomes into one setting. Students in this study reflected that they were simultaneously learning technical skills (e.g., computer skills, data analysis, and writing) and professional skills that support leadership development (e.g., networking, self-awareness, adaptability, and cultural empathy) in the same learning space. Findings from this work indicate that leadership development can occur simultaneously with technical development even through remote experiences. The methods used for equipping students with leadership-enabling competencies in this REU may be transferable to other REU sites and even engineering classes.

Findings from this work identified a variety of leadership-enabling competencies that students developed through a virtual REU experience that aligns with current engineering and construction industry expectations [5]. Further, findings from this work identify unique inclusive leadership competencies (e.g., patience, cross-cultural collaboration, cultural empathy, understanding of systemic barriers, and respect) that the students in this REU site self-identified as outcomes of their virtual summer research experience. Through faculty seminar networks, journal clubs, reading the literature on diversity and inclusion in engineering, and collaborating with diverse teams of projects seeking to expand inclusion in engineering, these students developed and practiced skills that align with the traits required of inclusive leaders (e.g., awareness of bias, curiosity about others, cultural intelligence, and effective collaboration) [22]. These students were able to practice Inclusive leadership by ensuring individuals on their projects feel valued for their contributions and all demonstrated commitment to reduce bias and employ empathy and understanding for all [20], [22]–[24]. This work contributes to the growing body of literature on inclusive leadership by outlining the perceived skills students developed and practiced by participating in this virtual REU program.

Further, this work indicated that students were gaining critical leadership-enabling competencies over a remote research experience. This aligns with prior work that suggests that remote REU sites are effective in helping students develop confidence, knowledge, and an increased desire to pursue further research experiences [30]. Intentional development of virtual research experiences is key to successfully integrating leadership and professional development into a remote learning environment [30]. To prepare for the future which may necessitate the need for more virtual or remote experiences the findings from this REU are critical to understanding how to properly engage students and support them in the development of leadership skills through a virtual research experience. In this REU, students found community hour, open discussion with mentors and faculty, journal club, online social events, and weekly meetings with mentors useful and instructive. The remote workspace even prompted students in this study to develop inclusive leadership skills such as cross-cultural collaboration and global teamwork.

As the engineering industry continues to expand and broaden participation across people of various backgrounds, identities, and cultures, inclusive leadership is becoming more of a prerequisite to entering the engineering workforce. Future engineers will need to be prepared to work with and serve a diverse group of people across the world. Inclusive leadership in engineering will require a future generation of leaders that are considerate and respectful when collaborating with people of different identities, backgrounds, cultures, and experiences. Regarding leadership-enabling competencies that support inclusive leadership, findings from this study indicate students in this REU were developing global teamwork, cross-cultural communication, and boundary-spanning skills. Global teamwork is becoming more and more of a necessity in engineering [37], [38]. “A growing body of evidence suggests that practicing engineers are increasingly expected to act as boundary spanners who can participate in and manage diverse local and global teams, translate competing stakeholder demands into effective design solutions, and leverage expert knowledge from multiple fields and specialties” [39]. Cross-cultural teamwork requires personnel with a variety of backgrounds and cultures to work together across time zones, cultures, and languages toward a common goal [40]. Boundary spanners must possess strong communication skills, set clear expectations and be respectful of various cultural norms and practices while collaborating toward that goal [40]. The findings from this paper indicate that students who participated in this REU were able to develop these

essential skills and practices working on cross-cultural teams even within the setting of a small but dynamic virtual REU site. Students worked together across time zones and various institutions and engineering disciplines on their projects. Many students were first-generation, and some had English as their second language. While students reflected on some of the difficulties of working in teams across the country and various time zones and disciplines, they also reflected on the organizational and management skills they were able to develop and practice throughout the course of the REU. Students worked diligently to assure they were planning and attending meetings in the correct time zone and being respectful of their peers and mentors' thoughts, opinions, and time. These findings address a call for more students to possess cross-cultural communication skills by understanding that these may be developed through virtual REU sites with interactions amongst and across students, faculty, and mentors of diverse identities, backgrounds, geographic locations, and disciplines. Prior research supports that these skills are best developed through practice and participation [37] and the REU program was successful in that students were able to learn and exercise a variety of inclusive leadership-enabling competencies.

Implications

If undergraduate faculty members and advisors continue to encourage their students to engage with out-of-class activities such as REU programs that will increase students' opportunities to develop an array of inclusive leadership skills. Faculty members and mentors of undergraduate researchers should consider how technical knowledge can be integrated into professional development through larger independent research projects in combination with technical training, workshops, reading assignments, community discussions, and seminars led by leaders in industry and academia.

Future REU site organizers, leaders, and mentors of undergraduate researchers should consider the current trends in research and industry and continually improve their programs to offer students more opportunities to develop new skills for the future of engineering research and industry. If REU site organizers considering virtual or remote options explore the best practices of engaging students virtually as well as being transparent about the challenges and skills that students may encounter and develop by participating in a virtual research experience they will be successful in hosting a meaningful and impactful research experience. For instance, REU site organizers should consider implementing weekly reflections, community discussions, and learning/working experiences that encourage working on teams including individuals across various cultures, disciplines, and backgrounds. Inclusive leadership skills such as cross-cultural collaboration and boundary spanning should be prioritized when developing the REU site. Therefore, students from a variety of underrepresented backgrounds in engineering should be recruited to participate in the REU to broaden participation in engineering research and leadership and facilitate more opportunities for working with people of diverse backgrounds. Safe and inclusive spaces for students of underrepresented backgrounds should be present in engineering settings. Furthermore, faculty should work to promote opportunities for students to develop professional communication and networking skills through research presentations, poster sessions, discussions with other scholars or leaders, or attending conferences such as ASEE.

Undergraduate engineering students should consider the importance of using summer to get involved in an REU or participate in undergraduate research. Whether or not research is their end career goal, an undergraduate research experience can be useful in expanding their knowledge of the industry and helping them to develop essential leadership-enabling competencies for their future. Students who participate in these experiences will benefit by reflecting on the outcomes of their participation and incorporating the skills and knowledge they gained into their resume and interview responses when applying to graduate school, various awards, internships, or careers in the industry.

Limitations and Future Work

A limitation of this study is that qualitative research is never generalizable. This work focuses on the outcomes of an REU on the leadership development of 9 students from underrepresented backgrounds in engineering. However, findings may be transferable to other undergraduate researchers or REU sites. While 100% of the population in this study held at least one underrepresented identity in engineering (e.g., first-generation, women, Black, LatinX, low-income), it is unknown what the results would be in another setting. Researchers suspect similar outcomes in terms of leadership development may be applicable to those of all identities in engineering, but this would need to be examined. Further, this program was unique in that all the faculty and mentors also held at least one underrepresented identity in engineering. The representation of individuals from these underrepresented groups was intentional in improving representation and cultivating a safe space for students who are generally underrepresented in their engineering majors. This sharing of identity likely aided with leadership development and the comfort the students in the REU felt by asking questions and speaking up. This environment allowed for the physical appearance and inclusion of those that are typically underrepresented in engineering spaces. Further, the models used in this REU focused on promoting a safe space for underrepresented students to learn and grow and thrive in engineering research. It is unknown what the effect of this REU would have been on other populations.

Future research should further explore the best practices for integrating technical and professional learning outcomes into research programs and engineering classrooms. Further, work is needed to understand how these skills developed through research experiences or in the classroom are translated into practice in engineering industry positions. While findings from this work relied on self-reports and survey responses, future work could use observations and follow-up interviews to generate a deeper understanding of the leadership competencies developed from an REU program. Lastly, more research is needed to explore the methods and outcomes of developing inclusive leadership skills and educating the next generation of engineering professionals to promote inclusion and broaden participation in the field.

Conclusion

REU experiences offer engineering students additional opportunities to prepare for their future careers, whether they end up in academia or industry, and develop a set of unique skills that build their inclusive leadership “toolkit”. This leadership toolkit expands opportunities for students of underrepresented groups in engineering to develop as inclusive leaders and will prepare them for the future of engineering in the US. This study demonstrated that students who participated in this REU were able to develop both technical and professional knowledge simultaneously. Students developed as leaders and gained a knowledge of the engineering

industry and career pathways, intrapersonal growth, interpersonal relationships, digital literacy, and communication skills throughout their time in the REU. This exhibits that an REU is not only useful for recruiting and preparing students for graduate school or academia, but also for leadership in a variety of careers including but not limited to research, academia, engineering industry, teaching, construction, consulting, and entrepreneurship.

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