Investigating the Influence of Being a Mentor on Leadership Development among Engineering Graduate Students and Postdoctoral Scholars

by

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ABSTRACT

Leadership is an essential component of engineering career success, yet early-career engineers report a lack of leadership skills entering the workplace. Studies have suggested that mentoring opportunities have the potential to provide an alternative approach to learning and practicing leadership. What is not yet understood is to what extent and in what ways serving as a mentor develops leadership.

This dissertation fills this knowledge gap by sequentially conducting qualitative and quantitative studies examining how serving as a research mentor influences engineering graduate students and postdoctoral scholars' leadership understanding and competencies. Study participants were recruited from short-term research programs offered by National Science Foundation (NSF)-funded Engineering Research Centers (ERCs). A total of 17 former ERC mentors and 75 current ERC graduate students and postdoctoral scholars participated in the qualitative study and the quantitative study, respectively.

The results suggest that serving as a research mentor can help to advance leadership understanding and competencies. The qualitative study discovered that former ERC mentors believed they gained new perspectives of leadership and developed their leadership competencies while serving as a mentor. This included a growth in awareness of importance to express empathy toward other people and ability to develop others and delivering project results. The quantitative study demonstrated that ERC mentors reported higher competencies in leading other people and delivering project results compared to their peers who had not served as mentors. ERC mentors still primarily connected leadership to leaders, despite the noted gains. This finding indicated the ERC

mentors have not yet fully captured the true essence of leadership. The overall evidence suggests that serving as a mentor in a short-term program provided an effective and efficient opportunity for ERC graduate students and postdoctoral scholars to further their understanding of what it means to be a leader and improve their competencies of being a good leader. Such experiences left much to be desired in establishing a social, processual view on leadership.

DEDICATION

This dissertation is dedicated to my grandmothers, Guizhen Li, and Jianni Sheng, both of whom unfortunately passed away as I got close to the finish line, and my parents, Quqing Zhao and Mei Zheng, for their unwavering support, love, patience, and encouragement throughout my life. Thank you for always being by my side. No effort on my part will ever be enough to thank you for the sacrifice you have made on my behalf.

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As a student of ASU, I acknowledge that the Tempe campus sits on the ancestral homelands of those American Indian tribes that have inhabited this place for centuries, including the Akimel O'odham (Pima) and Pee Posh (Maricopa) peoples.

As noted by President Crow (August 31, 2015), "In keeping with the design aspirations of the New American University, ASU seeks to embrace our place, connect with tribal communities, and enable the success of each American Indian student. We reaffirm the university's commitment to these goals and acknowledge that everyone, the entire ASU community, is responsible for their achievement."

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CHAPTER 1

INTRODUCTION

Calls about the importance of leadership in an engineering career have appeared within both academia and professional communities (Mohan et al., 2010; Ellis & Petersen, 2011; Ahn et al., 2014; Froyd & Borrego, 2014). Professional engineers spend over half of their working time doing leadership and other professional skill-related tasks (Mohan et al. 2010), which makes leadership a key component of engineering career success (Ellis & Peterson, 2011; Ahn et al., 2014; Froyd & Borrego, 2014). Electronic Engineering Times reports that 77% percent of professional engineers surveyed reported experiences having to act as team leaders on the job (Bellinger, 2002). The importance of leadership on the job has not translated into engineering education as early-career engineers typically enter the engineering workforce with underdeveloped leadership skills (Kumar & Hsiao, 2007). Engineering students' leadership competencies lag other fields (Stephens & Rosch, 2015) and what is expected by industry (Mohan et al., 2010). This has resulted in engineers often being left out of senior management position promotions compared to their co-workers with MBA or JD degrees because they lack adequate leadership and communication skills (Summers et al., 2004). Such skills must instead be acquired on the job to fill the gap (Kumar & Hsiao, 2007; Farr & Brazil, 2009).

Industry leaders (Heilmeier, 1995) and engineering education scholars have expressed the need for leadership training and teaching in engineering education to combat these issues and note that such training and teaching opportunities have been long overlooked by the engineering community (Russell & Stouffer, 2005; Seemiller &

Murray, 2013). Leadership was recently added in Fall 2019 to the ABET revised criteria 3 student outcomes for accrediting engineering programs (Karimi & Manteufel, 2020). An ABET-accredited engineering program expects to now develop students with "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives" (ABET, 2019). Educators have simultaneously called for innovative ways to introduce and impart leadership concepts to engineering students at all levels so that such learning does not further burden the already dense engineering curriculum (Kumar & Hsiao, 2007; Simmons et al., 2017). Studies have suggested that serving as a mentor can provide an alternative approach to developing leadership (Dolan & Johnson, 2009; Rottmann et al., 2014; Limeri et al., 2019). Work to explore the impact of serving as a mentor on developing leadership within the field of engineering has been limited outside of the author's preliminary work (Zhao & Carberry, 2018). This leaves a gap in the literature and a need to explore the impact of serving as a mentor on leadership development within an engineering context (Lee et al., 2020).

This dissertation research is intended to explore how serving as a mentor in engineering research setting influences mentors' leadership development. The work is accomplished through a sequential two-phased approach (Creswell & Clark, 2007): 1) a qualitative study exploring the influence of serving as a mentor on the development of leadership for former graduate student and post-doctoral mentors, followed by 2) a quantitative study to confirm and analyze the extent to which the emergent qualitative findings hold for current graduate students and postdoctoral scholars. The sequential design best fits the dissertation because little is known about how serving as a mentor

impacts leadership development and career preferences among engineering graduate students and postdoctoral scholars. The first-phase qualitative study explores this space in depth to provide a foundation for the second-phase quantitative study designed to create an instrument for broader exploration.

The context for this dissertation study is National Science Foundation (NSF)-funded Engineering Research Center (ERC) summer programs. ERCs offer one source of opportunities for engineering graduate students and postdoctoral scholars to serve as mentors in an engineering research setting. Summer research interns include high school students, undergraduate students, and K-14 educators (National Science Foundation (NSF), 2021; NSF, 2022a; Sharp et al., 1994). These mentoring experiences take place in lab settings where a training procedure and conceptual mentoring model are used to guide the experience (Chandler & Larson, 2017). Variations can occur based on the program and technical focus of the ERC. Mentors from different centers have equivalent mentoring responsibilities. The relatively homogeneous mentoring experiences from these programs make ERC summer research program mentors an interesting population to study.

CHAPTER 2

BACKGROUND

This dissertation studied engineering graduate students and postdoctoral scholars in a short-term research mentoring setting that happened within NSF-funded ERCs. Leadership development is extremely important for engineering graduate students and postdoctoral scholars because these individuals are more likely to end up in leadership positions during their careers. Engineering graduate students and postdoctoral scholars also have engaged in more mentoring opportunities and experiences compared to undergraduate students. NSF ERC summer research programs provide formal mentoring opportunities for engineering graduate students and postdoctoral scholars (NSF, 2021; NSF, 2022a; Sharp et al., 1994). These mentoring opportunities are homogenous in nature, abut are also diversified by the technical context of the ERC. ERC summer program mentors and mentees go through four phases over time: 1) establishing, 2) growth, 3) performance, and 4) finalizing (Revelo & Loui, 2016; Chandler & Larson, 2017). The amount of explicit instruction provided by mentors to mentees gradually decreases from phase-to-phase, while assistance and encouragement start low, increase, and then gradually decrease back down (Revelo & Loui, 2016; Chandler & Larson, 2017). These features embedded in a mentoring experience make ERC summer program mentoring opportunities unique research setting to study the broad impact of mentorship on leadership development for engineering graduate students and postdoctoral scholars.

NSF Engineering Research Center

The National Science Foundation (NSF) has funded 75 Engineering Research Centers (ERC) since 1985 and is currently supporting 15 active centers (National Science Foundation (NSF), 2022b). These ERCs have been leading forces in conducting advanced, complex multidisciplinary research to address critical science, engineering, and technology challenges (NSF, 2022b). ERCs strive to converge research, education, and technology translation at U.S. universities to make strong societal impacts (NSF, 2022b). Other core features of ERCs include improving engineering education experiences for students, enhancing engineering exposure to the general public, encouraging diversity in the STEM workforce, and connecting industry with academia (NSF, 2022b).

Engineering Research Center Summer Programs

ERCs provide summer research opportunities for high school students, undergraduate students, pre-college teachers, and community college instructors to conduct advanced science and engineering research leveraging the resources in the center sites (NSF, 2021; NSF, 2022a; Sharp et al., 1994). These opportunities have included, but are not limited to, Research Experiences for Undergraduates (REU), Research Experiences for Teachers (RET), and Young Scholars Programs (YSP). The REU program supports undergraduate participation in scientific and engineering research. The goal is to prepare these students for careers in science and engineering. The program typically lasts 8 – 10 weeks (NSF, 2022a). The Research Experiences for Teachers (RET) program supports the active involvement of pre-college teachers and community college

instructors in engineering research to bring knowledge of engineering and technological innovation back to their classrooms. Teachers are also required to generate curricula and teaching plans based on their in-program research experience, which usually lasts for 6 – 8 weeks (NSF, 2021). The Young Scholars Program (YSP) is designed to inform and excite high school students about science, engineering, mathematics, and technology and to encourage them to investigate and pursue careers in these fields. The experiences vary in length from 3 – 8 weeks (Sharp et al., 1994).

ERC summer research programs offer voluntary mentoring opportunities to center-affiliated graduate students and postdoctoral scholars by assigning them as research mentors to summer interns. Mentors of these programs are asked to develop a plan to: 1) teach summer interns research-related knowledge and skills, 2) engage summer interns in scientific and engineering research, 3) support summer interns in navigating technical issues, 4) advise on summer interns research projects, 5) develop summer interns competencies and professional skills as researchers, and 6) encourage continued interaction following the summer experience between mentors and summer interns. The mentoring training received by these mentors varies from little or no guidance to week-long mentor training (Chandler & Larson, 2017).

Leadership, Leading, and Mentoring

The concepts of leadership, leading, and mentorship are complex and defined in a variety of ways in literature. The following subsections define these terms for clarity throughout the rest of the dissertation.

Leadership

Traditional leadership research takes a heroic view of leadership, describing leadership as an attribute of individuals who are considered leaders (Denis et al., 2012). Focus is often placed on what leaders do, including their qualities, behaviors, and effectiveness (Denis et al., 2012). A research stream with an "interactional, communicational, relational, emergent, and processual view of leadership" has emerged since the mid-2000s (Denis et al., 2012). This stream believes leadership is a property of a group rather than individuals (Denis et al., 2012, p.267; Hollander & Julian, 1969). Leadership viewed through this lens leverages a process ontology and moves away from the heroic perspective (Wood, 2005). This often-labeled "post-heroic leadership" view regards leadership as an outcome generated through a process in which individuals socially interact with others (Denis et al., 2012). Leadership becomes a consequence or product of individuals' actions, reactions, and interactions within the group. This outcome includes three major components: direction, co-orientation, and action space (Crevani et al., 2007). Direction is the common direction produced in leadership social interaction. Co-orientation is "enhanced understandings of possibly diverging arguments, interpretations and decisions of all involved parties". Action space is "construction of possibilities, potentials, opportunities and limitations for individual and collective action within the local-cultural organizational context" (Crevani et al., 2007, p.81)

The overall process is iterative as leadership is iteratively created and recreated throughout. The heroic view of leadership sees leadership occurring when leaders take on actions to lead, while the post-heroic view of leadership believes leadership occurs when

leaders stop controlling and dominating in lieu of letting themselves engage in the routine daily interactions within the group (Denis et al., 2012).

This dissertation defines leadership as a social process of influence in which all people interact (Chandler J. L., 2018; Chemers, 2014). Such a process emerges automatically and iteratively within groups (Denis et al., 2012). This definition is used both in analyzing the qualitative study data and in developing the quantitative instrument. The prescribed definition reflects the trend in engineering leadership research that leadership should not be defined as a title or position but a process that occurs among leaders, followers, and/or team members (Komarek, 2022). The process-viewed definition shifts the responsibility from certain individuals who hold the "leader" position to the collective group (e.g., team, organization, or even the society), and also places greater value and emphasis on the contributions and expertise of all individuals within the collective (Komarek, 2022).

Promoting leadership as a social process rather than positional definition of leadership matches the need for leadership development within the engineering workforce. The positional perception of leadership hinders leadership development among those in the engineering workforce. Rottmann et al. (2014) argued that professional engineers perceive leadership to be a position or a title therefore not of their identity. These findings conflict with the fact that most engineering professionals conduct leadership behaviors daily. This misconception has resulted in professional engineers' lacking a sense of belonging when talking about leadership. Engineers should embrace the discussion of leadership because it is part of what they do every day (Rottmann et al., 2014). The lack of resonation with leadership might be an underlying cause for why

engineers rarely get promoted to management positions (Summers et al., 2004). The positional view of leadership could also discourage engineers to get involved in and contribute to teamwork. They may want to contribute but cannot see how to do this if they do not see themselves as a leader. The positional view of leadership could cause engineers to question their roles in the workplace, which impacts their sense of belonging to an engineering team.

The interaction, processual view of leadership suits engineers better in organizational settings. Raelin (2005) used the term "leaderful" to describe the situation in which every member of a group is participating in the leadership together and concurrently rather than sequentially. Raelin (2005) believes that leaderful practice is more appropriate to the modern organization where the knowledge workers are more involved in the daily operation, which shifts the organizational structure from vertical to horizontal. Workers with engineering knowledge are present throughout most organizations and take a crucial role in the success of the organization (Raelin, 2005). Modern-era organizations are successful because they provide opportunities and infrastructures to leverage the technical expertise, problem-solving abilities, and engineering mindset of their engineering knowledge workers. These infrastructures include flattening the organizational structure and opening the boundaries for engineers. Engineers who work in such organizational settings will need to have the ability, awareness, and comfort to identify the opportunity, engage in the process, and interact with others to participate in the creation of leadership.

Leading

Leading is an integrated action that individuals enact while engaging in the leadership process (Chemers, 2014). Leading itself is part of the group social interactions that were mentioned in the leadership definition. Individuals in a group adopt various actions during social interaction that will influence and ultimately contribute to the emergence of leadership. These actions include, but are not limited to, communicating, analyzing, synthesizing, decision-making, position-taking, empathizing, persuading, manipulating, threatening, lying, etc. Leading also can be conducted intentionally and/or unintentionally. Leading doesn't guarantee a positive direction or satisfactory organizational outcomes. Individuals can attempt to lead to achieve very selfish or unethical goals that may hinder the group's achievement, but this action is still leading. Crevani et al. (2010) pointed out that leadership interactions can be detrimental and even unethical. They observed dysfunctional group dynamics through a case study where the hypocrisy and value conflicts within the project team, decreasing the team members' mutual understanding. The leadership that emerges could equip an organization with both positive and negative (or even neutral directions) that are not necessarily toward or in alignment with the common goals believed to be part of a traditional leadership ontology (Drath, et al., 2008). This dissertation focused on the actions resulting in people working together effectively to deliver favorable results and attain valuable common goals, rather than the actions that can create problems.

Mentoring

Mentoring is defined as a relationship among multiple individuals who work together, where more-experienced individuals help less-experienced individuals grow in both their personal life and professional career (National Academy of Sciences, Engineering, and Medicine [NASEM], 2019; Lee et al., 2020). Mentoring involves four types of behaviors or functions: career advice, psychosocial support, role modeling, and work assignment supervising (Scandura & Viator, 1994; Haggard et al., 2011). Scandura and Viator (1994) concluded a mentoring relationship has three main functions: career development, psychological support, and role modeling, while Haggard et al. (2011) further discussed supervisory mentoring relationships and provided the extra function of non-supervisory mentoring.

This definition of mentoring aligns with this dissertation's study population in that the more-experienced individuals (e.g., graduate students and postdocs) helped less-experienced individuals (e.g., high schoolers, undergraduates, and pre-college teachers) to develop research experiences and expertise during an NSF-funded Engineering Research Center (ERC) summer program mentoring experience. ERC summer program mentors have a responsibility to monitor the program interns' project progress and make sure they deliver results. These extra mentoring responsibilities extend the mentoring boundary in the ERC summer research setting to supervisory mentoring, which is covered by the fourth mentoring function in this definition.

CHAPTER 3

LITERATURE REVIEW

Literature on engineering leadership education, and mentor gains provided the foundation for this dissertation. Research exploring engineering leadership education inspired the discussion and promotion of serving as a mentor as an alternative approach to developing leadership for the engineering workforce. Literature on mentor gains then paved the way to take an extended look at leadership development being a benefit of mentoring others.

Engineering Leadership Education

The National Academy of Engineering's calling for engineering leadership education reform has led to a wide variety of ways to deliver leadership education in engineering settings (Rottmann et al., 2014). These approaches include but are not limited to leadership courses (McCuen, 1999), interdisciplinary team projects (Cain & Cocco, 2013), service learning (Huff et al., 2016), problem-based learning (Kumar & Hsiao, 2007), mentoring (Graham et al., 2009), professional learning communities (Athreya & Kalkhoff, 2010; Simpson et al., 2012; Osagiede et al., 2013), industry-sponsored opportunities (Graham et al., 2009; Lockheed Martin, n.d.), and multi-institutional collaboration (Huff et al., 2016).

Many researchers have pointed out the importance of embedding leadership education into the engineering curriculum (Rottmann et al., 2014; Knight & Novoselich, 2017; Perry et al., 2017). Some countries (e.g., Canada and many in Europe) have made it common place to integrate leadership education content into the core engineering

curriculum (Graham et al., 2009). Integration of leadership education components into the engineering curriculum can help engineering students and faculty to gain an awareness that engineering is a profession that benefits from individuals having an awareness of leadership (Rottmann et al., 2014). Teamwork-based, project-orientated engineering courses (Zafft et al., 2009; Novoselich et al., 2016; Kendall et al., 2018; Komarek et al., 2018) develop leadership competencies by offering practical experience to exercise professional skills. This includes capstone courses, which add another layer of leadership development experiences that provide students with the opportunity to collaborate with industry to solve real-world problems (Abdulwahed & Hasna, 2017). Perry et al. (2017) further argued that engaging students in project experiences is just the first step. More designs and structures need to be established to fully integrate leadership into the highly technical engineering curriculum (e.g., requiring students to be involved in strategic planning to carry out projects, encouraging students to foster systems thinking, and planning specific opportunities to expose students to interdisciplinary knowledge). For example, Kumar and Hsiao (2007) provide a course incorporating leadership learning and practice opportunities through problem-based learning and service-learning concepts. The course incorporated learning the concepts of geotechnical engineering in professional practices alongside learning and practicing leadership. Students formed teams and worked as a team in the course. All teams worked on the same level of real-world projects with technical complexity like that of professional engineers with two to three years of experience. The selected projects also provided students with opportunities to practice leadership skills, communication skills, and ethics.

Alumni rated the course very positively and credited the course as a reason for their early career success.

Stand-alone leadership programs are more common in when examining engineering education within the United States (Graham et al., 2009). Leadership programs are parallel to the engineering core curriculum, but also allow students to practice leadership in a non-engineering course setting. Leadership programs provide engineering students specialized curricular opportunities that relate to leadership development such as academic degrees, professional certificates, and individual courses (Graham et al., 2009, Kendall et al., 2018; Klassen et al., 2016).

Huff et al. (2016) explored leadership in engineering education by shifting the focus away from a purely curricular effort to a service-learning design program. The authors conducted a sequential mixed-methods study on Engineering Projects in Community Service (EPICS) alumni to examine the perceived impact of the program on their preparation for workplace practices. The study began with a survey of over 523 participants, followed by 27 interviews that were thematically analyzed. Study results revealed EPICS, as a service-learning program, provided opportunities for participants to practice workplace responsibilities and helped alumni develop a wide range of professional skills, including leadership skills.

The work undertaken by Kumar and Hsiao (2007) and Huff et al. (2016) demonstrates the impact that curricular-based programming can have on engineering leadership education, but the incorporation of leadership learning and practice through such mechanisms reveals many issues. The first issue is fitting leadership into engineering curricula. Most engineering curriculum is already quite full (Simmons et al.,

2017). Adding additional requirements to the curriculum could result in an overload for students seeking their degree in four years. Some programs have designed engineering leadership programs, which can present additional curricular issues. Graham and colleagues (2009) reviewed 40 engineering leadership programs around the world and concluded that the content taught in these programs is not balanced between theory, projects, and coaching. These programs tend to lack resources, expertise, and strong community support. ERCs present one possibility for addressing such issues by leveraging abundant available resources, industry partnerships, academic networks, and institutional support using a co-curricular approach. Emergent programming could be developed using the ERC platform, including specialized leadership development opportunities, mentoring programs, and other co-curricular supplements.

Another issue is engineering leadership education is the primary adoption of a leader-centered philosophy rather than a social interaction and culture-centered approach (Crevani et al., 2010; Day et al., 2014). Simmons and colleagues (2017) selected and reviewed 36 articles published between 2001 and 2014 examining leadership development and practices in civil and construction engineering. The meta-analysis demonstrated how the civil and construction engineering fields still followed the leader-centered skills development form, which does not reflect an emphasis on leadership development (e.g., creating a culture of better team play or leadership and followership transitions between team members). The authors proposed four action steps for future engineering leadership education: 1) develop a clear, value- and culture-laden definition of leadership, 2) embed leadership development content into existing courses and professional development, 3) formalize leadership development from co-curricular and

extracurricular involvement, and 4) evaluate leadership competencies using valid and reliable instruments. The findings and suggested actions of Simmons et al. (2017) are not surprising, as leadership researchers have previously identified the same pattern across other disciplines. These findings initiated a shift in focus from leader-centered practices to leadership practice and social interaction (Crevani et al., 2010; Day et al., 2014), as well as team leadership (National Research Council (NRC), 2015).

A change of focus in both engineering leadership research and education recently occurred after leadership was directly added to the ABET student outcome criteria (Mustafa, 2020; Baine et al., 2020; Imbrie et al., 2020). Student outcome five in ABET clearly stated that an engineering institution needs to foster students with "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives" (Accreditation Board for Engineering and Technology (ABET), 2019). ABET's (2019) focal point on leadership is that leadership needs to be discussed under the context of teamwork rather than individual leading practices. ABET (2019) clearly stated that the team members work together to provide leadership rather than certain individuals leading the team. This team-lensed leadership understanding aligns with Simmons et al.'s (2017) argument.

Recent studies, especially the work from Baine et al. (2020) and Imbrie et al. (2020), continued the focus of engineering leadership being team leadership rather than individual leadership. Baine et al.'s work (2020) captures group management, group collaboration, group inclusivity, team established goals and task planning, and team achievement of objectives. Imbrie et al.'s work (2020) assesses the team's ability to work

together on tasks to develop learning, establish shared beliefs, and set goals. This team perspective differs from existing engineering leadership instruments (Ahn et al., 2014; Yoon et al., 2016; Komarek, 2020) that measure individual student's ability to motivate and develop team members, create and share visions, establish and communicate goals, and involve team members to work together on tasks.

The summation of the literature exploring engineering leadership education suggests there is still work to be done to improve and incorporate leadership learning and practice opportunities into student experiences in engineering education programs. A focal point around leadership development from formal engineering mentoring experiences has yet to be explored. Exploring formal mentoring opportunities as a contributory approach to engineering leadership education aligns with the third action steps proposed by Simmons et al. (2017) for future engineering leadership education.

Simmons et al. (2017) proposed to establish leadership development opportunities from cocurricular and extracurricular activities, given how dense the engineering curricula already are. This dissertation study explores opportunities to teach and/or develop leadership through co-curricular activities. The use of co-curricular activity settings is intended to reach a larger postdoctoral scholar and graduate student population, particularly because leadership development opportunities (e.g., leading a social or academic club or organization) are not always readily available to most postdoctoral scholars and graduate students. Co-curricular activities do not equate to zero curricular components being developed, but rather leadership being developed and applied alongside existing curricula to avoid the addition of extra courses. NSF ERCs still use their resources and network to implement adequate curricular opportunities to teach

and develop leadership among their engineering graduate students and postdoctoral scholars when involving them in the co-curricular activities.

Mentor Gains

The bulk of research examining mentorship opportunities has explored mentor gains in an organizational and/or vocational setting (Ragins & Scandura, 1999; Higgins & Kram, 2001; Allen & Eby, 2003; Allen et al., 2004; Bozionelos, 2004; Eby & Lockwood, 2005; Allen et al., 2006; Allen, 2008; Ghosh & Reio Jr., 2013). Reported mentor gains include gaining new knowledge (Eby & Lockwood, 2005; Higgins & Kram, 2001), improving job performance (Eby & Lockwood, 2005; Ragins & Scandura, 1999), increasing personal gratification (Allen et al., 2004; Eby & Lockwood, 2005), developing new personal relationships (Eby & Lockwood, 2005), obtaining recognition (Ragins & Scandura, 1999), job satisfaction/commitment (Ghosh & Reio Jr., 2013), and career success (Bozionelos, 2004; Allen et al., 2006; Allen, 2008)

A comparably limited number of studies have focused on graduate student-level mentor gains (Dooley et al., 2004; Dolan & Johnson, 2009; Horowitz & Christopher, 2013; Hayward et al., 2017; Zhao & Carberry, 2018; Limeri et al., 2019). This includes recent studies that have expanded the focus on graduate student mentors in STEM research settings (Dolan & Johnson, 2009; Horowitz & Christopher, 2013; Hayward et al., 2017; Limeri et al., 2019), including the authors' earlier work (Zhao & Carberry, 2018). Improved interpersonal skills and career preparation were concluded as major gains to engineering mentors.

Dolan and Johnson's (2009) work explored motivations, benefits, and challenges for STEM postdoctoral scholars and graduate students who mentored in STEM research settings at a research university. They interviewed eight mentors (one postdoctoral scholar and seven graduate students) from a life science research group who had direct daily interactions with undergraduate students throughout the mentoring process. Gains reported by mentors through interviews were categorized into five groups: 1) instrumental gains (e.g., improved research ability and productivity), 2) socioemotional gains (e.g., increased enjoyment of work-life experience), 3) interpersonal gains (e.g., improvement in mentoring, teaching and communication skills), 4) professional gains (e.g., understanding of faculty work and potential careers), and 5) cognitive gains (e.g., intellectual growth and a deeper understanding of engineering concepts).

Hayward et al. (2017) built on Dolan and Johnson's work (2009) by expanding the research focus toward advising undergraduate student research. A sample of 30 STEM graduate students, postdoctoral scholars, and faculty were interviewed to explore potential motivations, benefits, and costs of choosing to advise undergraduate researchers. The majority of advisors reported benefits from an intrinsic perspective, which included improving professional skills, deepening the understanding of scientific knowledge/concepts, and invigorating the lab working environment. Instrumental benefits were expressed by participants as well, but to a lesser extent. These included improving research productivity and preparing for future faculty careers. A few early-career advisors notably mentioned only instrumental benefits during the interviews.

Dolan and colleagues later revisited their initial work with an expanded, multi-institutional sample (Limeri et al., 2019). A sample of 35 postdoctoral scholars (n = 7)

and graduate student (n = 25) mentors from 10 different public and private research universities across the United States were interviewed to explore their perceived benefits and costs of serving as a mentor as well as their motivation to mentor. Findings from Dolan & Johnson (2009) and Hayward et al. (2017) were introduced and used as a priori coding categories. The participants reported an improvement in interpersonal skills for engineering postdoctoral scholars and graduate student mentors. Career preparation was also mentioned as part of mentor gains. Postdoctoral scholars and graduate student mentors reflected on a new understanding of potential career options and improved confidence toward success in certain careers.

The work undertaken by Hayward et al. (2017), Dolan & Johnson (2009), and Limeri et al. (2009) all focused on long-term engineering research mentoring experiences, which extended at least a year. Zhao and Carberry (2018) shifted the focus toward investigating the impact of a short-term engineering research mentoring experience on mentors' skill development. The study specifically focused on engineering postdoctoral scholars and graduate students who had served as mentors to high school students, undergraduate students, and K-14 teachers in short-term summer research programs offered annually by NSF-funded ERCs. Participants were recruited from three institutions affiliated with a single NSF ERC. The quantitative analysis revealed that engineering postdoctoral scholars and graduate students who have served as mentors in at least one summer engineering research setting reported gaining significantly more mentorship skills through their ERC experience compared to their peers who never served as mentors in the ERC programs. Semi-structured interviews were also conducted with two postdoctoral scholars and six graduate students who served as mentors in the

summer engineering research setting to investigate whether the quantitative findings resonated with these mentors. The qualitative data confirmed the quantitative findings and provided insights into how serving as a mentor in summer research programs helped engineering postdoctoral scholars and graduate students develop as mentors.

The summation of the work presented by these efforts to explore mentor gains revealed different benefits from different mentor groups. Professional skills development emerged for all studies, including specific mentioning of leadership skill development in Dolan & Johnson (2009), Limeri et al. (2019), and Zhao & Carberry (2018). Mentoring, communication, collaboration, and leadership skills emerged as the primary interpersonal skills discussed in these studies. Zhao and Carberry (2018) observed certain engineering graduate student and postdoctoral scholar mentors mentioning gains toward improved leadership skills.

Impacts on leadership skill development via mentoring presents an interesting alternative mechanism for graduate students to improve their understanding of leadership. This has yet to be further unpacked in graduate education, but a few studies have specifically explored undergraduate mentors' leadership development through mentoring others (Kim, 2007; Komives et al., 2009; Dugan & Komives, 2011; Campbell et al., 2012; Hastings et al., 2015; Walters & Kanak, 2016; Lee et al., 2020). Enlarged leadership capacities (Komives et al., 2009; Dugan & Komives, 2011; Campbell et al., 2012; Lee et al., 2020), increased levels of generativity (Komives et al., 2009; Hastings et al., 2015; Lee et al., 2020), advanced leadership philosophy (Walters & Kanak, 2016), and improved leadership competencies (Kim, 2007; Walters & Kanak, 2016) were discovered in these studies.

Emergent findings from examinations of leadership development among undergraduate mentors suggests a greater focus should be placed on how mentoring experiences can impact leadership development for graduate students. A focal point around leadership development garnered through mentoring experiences among engineering graduate students and postdoctoral scholars has yet to be fully explored. Leadership development is a critical skill for undergraduate students, graduate students and postdoctoral scholars. Engineering graduate students and postdoctoral scholars are more likely to end up in leadership positions when entering their professional careers. They are more likely to be requested to perform leadership related tasks during daily work, such as leading project teams and developing other colleagues. This research aims to address this gap by exploring what aspects of leadership engineering postdoctoral scholars and graduate student gain from mentoring experiences.

CHAPTER 4

CONCEPTUAL FRAMEWORK

This dissertation focused on leadership understanding and leadership competencies as they relate to leadership development. Two conceptual frameworks were used for the dissertation to guide the research: 1) Leadership Understanding Framework, and 2) Leadership Competency Framework. These frameworks were chosen or developed on a foundation informed by existing conceptual models and literature.

Leadership Understanding Framework

Chandler (2018) suggests an emphasis should be placed on "leadership structure, understanding, and practices" in leadership research within an Engineering Research Center (ERC) research setting. People-centered concepts of "understanding" and "practices" were chosen for this dissertation over an organization-centered concept of "structure" as it aims to explore engineering graduate student and postdoctoral scholar mentors' experiences and perceptions. The Leadership Identity Development (LID) (Komives, et al., 2009) model aligns with this view and was used to inform leadership understanding (Table 1). The LID model demonstrates a clear transition of an individual's understanding of leadership from a positional view to a relationship and process-oriented view. The positional view of leadership was recognized as a norm among the engineering workforce (Rottmann et al., 2015; Simmons et al., 2017), while the relationship and process-oriented view has been a new trend in the engineering leadership education literature (Komarek, 2022). The LID model provided a theoretical

structure to help capture the current status and change of leadership understanding among engineering graduate students and postdoctoral scholars.

Table 1.

LID Model Stages and Typical Views of Leadership

Stage	Typical Leadership Understandings
1	There is leadership out there but has nothing to do with me. National leaders or authority figures are the leadership.
2	I myself can involve in leadership activities and take responsibility for the leadership.
3	The job of leaders is to get things done. Leadership is a positional role that is held by certain people and only leaders do leadership.
4	Leadership happened everywhere within the group, not just from someone in a certain position, which is essential for good group processes/ results. Leadership is a group process. Everyone can influence the group regardless of their roles.
5	Leadership is generativity. leadership is a personal passion. Leaders should accept the responsibilities to promote team learning and develop other people to also become leaders. Develop others to also become leaders to sustain the organization.
6	Leadership needs continuous self-development and lifelong learning. Leadership calls for internal confidence in making changes, integrity, and the ability to address adversity. Leaders recognize their influence as role models to others.

The LID model summarized six sequential phases capturing the evolution of a person's leadership identity. Stage one centers on an *awareness* of leadership happening around an individual but an inability to connect themselves with the leadership observed. National leaders or authority figures are usually the only exposure to leadership an individual has at this stage. Stage two focuses on *engagement* by getting involved in group activities and taking responsibility. People begin to intentionally identify their strengths and weaknesses and gain confidence in their involvement in the group. Stage three focuses on *identifying* leaders and the skills that leaders need. People's awareness of leadership increases along with their further involvement in the group. They begin to identify leaders within the group (either themselves or someone else) as leaders and believe the job of leaders is to get things done. Leadership in this stage is seen primarily as a positional role that is held by certain people and only leaders do leadership. The key

term in stage four is *differentiation*. People at this stage gain the awareness that leadership happens everywhere within the group, not just from someone in a certain position. This shift in perception is essential for good group processes and results. This new awareness also includes learning how to effectively engage in, influence, and contribute to the group in non-leadership positional roles. A higher level of *generativity* is developed when someone reaches stage five. Individuals who have higher generativity have higher willingness to engage in developing other people and promote the wellbeing of younger generations. People start to look beyond themselves and pay more attention to others when thinking about leadership, especially how they can help others grow, learn, and succeed. Generativity expands leadership beyond just work/task/project contexts, but also into human and societal contexts. People whose leadership understanding reach this stage will extend their focus on developing, mentoring, and teaching the people around them to achieve sustainability within an organization, community, or society, rather than just delivering a good result of projects or tasks. Stage six is the last stage where people think of the meaning of leadership through the lens of *life adversity* and develop a perception that leadership is a *lifelong learning* and *self-development* process. The goal of leadership shifts from skills or behaviors to credibility and confidence in accomplishing changes for situations they may face in the future. The later stages (4-6) in LID model reflect an advanced understanding of leadership, which would help the engineering workforce to work more effectively in the workplace. This should lead to better contributions toward community building and achieving life goals.

Leadership Competency Framework

Seemiller (2013) defines competencies as the knowledge, ability, or practice that effectively contributes to a role or task. The chosen focus on competencies was informed by previous work in the engineering leadership development literature (Komarek, 2022). For example, the American Society of Civil Engineers (ASCE) published 25 articles focused on engineering leadership competencies between 1997 and 2017 (Handley at al., 2018).

The Framework for Leadership Competencies was comprised of leadership competencies and mentoring competencies drawn from multiple resources. McManus and Russell (1997) argued that transformational leadership and mentoring are a type of interpersonal relationship that involves personnel with varying degrees of experience. Scandura & Williams (2004) later mapped transformational leadership and mentoring using shared common competencies. The four dimensions of transformational leadership are – attributed charisma, idealized influence, individualized consideration, and inspirational motivation (Bass, 1990). *Attributed charism* depicts the scenario that other people resonate emotionally with leaders and are willing to go beyond their self-interest when following the leader. *Idealized influence* indicates that leaders create an atmosphere of trust and serve as role models to other people. *Individualized consideration* refers to leaders proactively offering other people learning and development opportunities. *Inspirational motivation* describes leaders motivating and directing people toward the achievement of the goal while encouraging people to challenge the leaders' way of doing things at the same time (Bass, 1985, 1990).

Scandura and Williams (2004) argued that transformational leadership and mentoring in organizational settings are linked to similar outcomes such as employee organizational commitment, work performance, and career expectations. First, *attributed charisma* and *idealized influence* portray a high level of respect that often occurs within a dyad relationship between mentors and mentees. This is due to the value mentees place on a mentor's capability to offer work or career assistance. Second, *individualized consideration* encourages transformational leaders to give one-on-one coaching to subordinates' unique developmental needs. Bass (1985) suggests this dimension is the strongest linkage to mentoring because mentors provide regular, individually focused advice within a mentoring relationship. Finally, mentors provide learning and development opportunities to mentees and motivate mentees to achieve their personal and career goals, which aligns with *inspirational motivation*.

This dissertation leverages connections between leadership and mentoring competencies following Scandura and Williams's (2004) work. Important to note is that the approach taken aims to show the connections between leadership and mentoring but does not equate the two terms. Leadership and mentoring are two different concepts despite the connections and similarities between the competencies (e.g., leadership is task-oriented and mentoring is people-oriented) (Scandura & Williams, 2004).

Leadership Competencies

Leadership competencies in a broader context were adopted in the framework as they are not based on any specific leadership model or style. The first resource considered was the Leadership Competency Builder (LCB) (Hiller et al., 2016)

copyrighted knowledge inventory, which provides a list of high-impact leadership competencies and is widely recognized by researchers and scholars in the leadership field. It was developed by a team of researchers at the Center for Leadership at Florida International University (FIU) through an extensive literature review and analysis of top-tier academic research literature in leadership dating back to 2015. LCB (Hiller et al., 2016) provides a list of "research-based, high-impact leadership competencies." The list includes 45 leadership competencies which were further categorized into five meta-competencies: 1) leading self, 2) leading others, 3) connecting with others, 4) providing strategic focus, and 5) delivering results.

Table 2 lists these five meta-competencies and all 45 subordinate leadership competencies. *Leading self* asks leaders to set good behavioral examples, including holding oneself accountable, taking initiative, and making the right decisions. Leaders also *lead others* by assigning appropriate roles to team members, motivating others to commit, providing professional development opportunities, rewarding contributions, encouraging collaboration, and building team cohesion. Leaders have to *connect with others* to accomplish their goals, which requires emotional intelligence and an ability to share information/resources, be a team player, be a good listener, and appreciate the differences among all team members including the leaders themselves. Leaders should *provide strategic focus* when leading an organization or a task. This involves taking a systematic view, creating shared visions and values, putting the right people in the right place, solving problems with creative and innovative approaches, and managing risks. The ultimate goal for an organization is to *deliver results* that satisfy stakeholders. Leaders are responsible for project management such as setting clear goals and planning

the tasks for the organization, providing technical expertise, managing resources, and tracking performance.

Table 2.

Leadership Competencies (Hiller et al., 2016)

Meta-competency	Competency
Leading self	1. Self-development 2. Judgment 3. Taking initiative 4. Honesty & Integrity 5. Self-confidence 6. Risk-taking 7. Perseverance 8. Accountability
Providing strategic focus	9. Systems perspective 10. Monitoring the external environment 11. Monitoring the internal environment 12. Thinking creatively 13. Visioning 14. Innovation and adaptability 15. Stakeholder orientation 16. Effective hiring and promoting 17. Image and reputation 18. Problem-solving skills 19. Crisis management 20. Corporate Social Responsibility
Connecting with others	21. Political acumen 22. Emotional intelligence 23. Supportive 24. Team player 25. Appreciation for differences 26. Networking 27. Upward and downward information sharing 28. Negotiation and mediation 29. Effective communication
Leading others	30. Influence 31. Team building 32. Clarifying roles and objectives 33. Managing team processes 34. Developing others 35. Appropriate use of authority 36. Providing rewards 37. Behavioral flexibility 38. Fostering collaboration
Delivering results	39. Urgency 40. Goal-setting 41. Monitoring performance 42. Planning 43. Delegation 44. Managing resources 45. Technical expertise

LCB also aligns with the engineering leadership competencies summarized in engineering leadership education literature. The list of such competencies typically include functional competencies like communication, collaboration in a team, taking initiative and personal attributes such as integrity, confidence, and adaptability (Hartmann & Jahren, 2015; Handley et al., 2018; Simmons et al., 2020).

The second resource considered was Handley et al. (2018) synthesis of the appearance of engineering leadership competencies among 25 related papers published by the American Society of Civil Engineers (ASCE) between 1997 and 2017. The resulting competencies and the frequencies of instance occurred are "communication (6), collaboration and teamwork (4), vision and direction (4), interpersonal skills (3), motivation (3), ethics and integrity (3), drive and initiative (3), organization and structure (3), decision making (2), time management (2), and technical knowledge (2)".

The third resource considered was Hartmann and Jahren (2015) study of job postings and interviews of industry representatives, which recognized five engineering leadership competencies as important for professional engineers by studying: communication, working well in a team, taking initiative, portraying confidence, and engagement in extracurricular and volunteer activities.

The final resource considered was Simmons et al. (2020) examination of the construction and civil engineering education literature, which identified 19 leadership competencies for construction and civil engineers: "communication, ethics/responsibility, professionalism, problem-solving, big picture thinking, ambition, self-awareness, humility, people focus, adaptability, collaboration, time management, management,

quality control, computer skills, risk management, assertiveness, legal knowledge, and economic principles/trends".

Mentoring Competencies

The NASEM report listed desired mentoring competencies that came from the Entering Mentoring Curriculum (Handelsman, et al., 2005; Pfund et al., 2015). The Entering Mentoring program is one of the most well-studied and well-known mentor education programs (NASEM, 2019). The effectiveness of the Entering Mentoring programs' ability to train mentors has been tested and researched both quantitatively and qualitatively across various STEMM disciplines and institutions (NASEM 2019). The report states the bidirectional characteristic of an effective and healthy mentoring relationship must include both mentors and mentees benefiting from the relationship and pointed out that the traditional mentorship model is mainly mentee-focused (NASEM, 2019).

This report illustrates six sets of mentoring competencies in a research training environment: 1) align expectations, 2) assess understanding, 3) communicate effectively, 4) address equity and inclusion, 5) foster independence, and 6) promote professional development. *Aligning expectations* includes three layers of behaviors: a) mentors specify their expectations for the mentorship relationship; b) mentors encourage the mentees to state their expectations out of the mentorship relationship and make the mentees feel safe and welcomed while speaking their minds, and c) mentors ensure the mentors' and mentees' expectations for the mentoring relationship are aligned. *Assessing the understanding* of mentorship asks mentors to understand mentees' knowledge and skill

level while planning for mentees to develop and succeed. *Communicating effectively* refers to instances when mentors listen to mentees, provide constructive feedback, identify and acknowledge the difference in communication styles between the two sides, then adjust themselves to accommodate mentees to achieve effective communication. *Addressing equity and inclusion* requires mentors to take into consideration the various background or identity differences between them and their mentees. Mentors should reflect on potential biases and assumptions they might hold and account for potential issues such beliefs may have during the mentorship relationship. *Fostering independence* means encouraging mentees to perform independent and creative work that builds their confidence and awareness toward themselves as valuable contributors. *Promoting professional development* suggests mentors work with mentees to help them set career goals, design and implement personal development plans and provide opportunities, guidance, and support for mentees to build a professional network. The report also specifically expressed the necessity for mentors to recognize the potential influence they have on mentees as role models through mentees' professional development.

Matching Leadership and Mentoring Competencies

The approach taken by this dissertation is to study leadership from the perspectives of conceptual understanding and action behaviors. The leadership competencies listed in the Leadership Competency Builder (Hiller et al., 2016) and mentoring competencies provided by The Science of Effective Mentorship in STEMM report (NASEM, 2019) were selected to build the competency matching framework because they best aligned with the chosen approach. The selection of the two resources

are based on the fit to the dissertation and the experts' view. The LCB (Hiller et al., 2016) provided a set of instantiated behavioral-based leadership competency items such as developing other people and delivering project results.

The National Academies of Science, Engineering, and Medicine (NASEM) report on the science of effective mentorship in science, technology, engineering, mathematics, and medicine (STEMM) (National Academy of Science, Engineering, and Medicine (NASEM), 2019), simialrly identified a group of instantiated action-based mentoring competencies that made the competency matching straightforward and direct.

Table 3.

Alignment between Leadership Competencies and Mentoring Competencies

LCB (Hiller et al., 2016)		Entering Mentoring Curriculum and NASEM report (Pfund et al., 2015)
Meta Competencies	Leadership Competencies	Mentoring Competencies
Providing strategic focus	Visioning Stakeholder orientation	Align expectations
Leading others	Developing others	Assess understanding Promote professional development
	Influence Providing rewards	Foster independence
Connecting with others	Appreciation for differences	Address equity and inclusion
	Supportive Team player Upward and downward information sharing Effective communication	Communicate effectively
Leading others	Behavioral flexibility	Communicate effectively
Leading self	Self-development Taking initiative Honesty & Integrity Perseverance Accountability	Influence as a role model

Table 3 demonstrates the matching between leadership and mentoring competencies created by examining the two resources. The adoption of the two competency lists in the dissertation was reviewed and agreed upon by scholars who have expertise in leadership and engineering mentoring. Matches are based on content rather than strict verbiage matching. The resulting framework demonstrates the overlap and similarities between leadership competencies and mentoring competencies, which provides a theoretical base to justify the study's exploration of how serving as a mentor influences leadership competency development among ERC graduate students and postdoctoral scholars.

The mentoring competency *Align expectations* was matched to the leadership competencies of *Visioning* and *Stakeholder orientation. Visioning* and *Stakeholder orientation* together are similar competencies for leaders as *Align expectations* is for mentors. *Align expectations* highlights that mentors and mentees can communicate freely about their expectations to each other and work together to make plans that ensure expectations from both sides can and will be met. *Visioning* talks about leaders receiving buy-in from the team and creating a shared vision for the team. The shared vision shall account for all team members' needs. *Stakeholder orientation* suggests leaders communicate with team members to make sure everyone's needs will be identified and delivered, which provides a foundation for the creation of a shared vision and values.

The mentoring competencies *Assess understanding* and *Promote professional development* were both matched with the leadership competency *Developing others. Promote professional development* and *Developing others* focus on developing, which includes mentors and leaders providing developmental feedback and helping others set

developmental goals, make executable plans, and access necessary resources. *Assess understanding* at face value seems to refer to something completely different relative to the other two competencies. Leaders need to know about other people's strengths and weaknesses if they want to help them develop, which is exactly what *Assessing understanding* is proposing. *Assessing understanding* also captures mentors helping mentees recognize and understand what they need to do next to achieve success (NASEM, 2019), which additionally ties to the aspect of developing others.

The mentoring competency of *Fosters independence* focuses on fostering mentees' independent work spirit, which includes scenarios where mentors motivate mentees to engage in work and acknowledge mentees' contributions (NASEM, 2019). This competency aligns with the leadership competency *Influence* where leaders use personal influence to motivate, inspire, and encourage others to commit to work (Hiller et al., 2016); and the leadership competency *Providing rewards* where leaders recognize and/or reward other people's effective performance and major achievements (Hiller et al., 2016).

The mentoring competency *Address equity and inclusion* aligns with the leadership competency *Appreciation for differences* because they both address the issue of mentors and leaders acknowledging, understanding, and respecting the differences in various aspects between them and mentees or team members.

The mentoring competency *Communicate effectively* includes four components for mentors: 1) active listening, 2) providing timely and constructive feedback, 3) recognizing the differences in communication styles between each side, and 4) adjusting communication styles to accommodate mentees. These four components match

leadership competencies of *Effective communication, Supportive, Upward and downward information sharing, Team player,* and *Behavioral flexibility. Effective communication* describes leaders listening to team members, which matches to the first component of the mentoring competency *Communicate effectively*. *Supportive* describes leaders showing support, empathy, and offering help to team members, which is equivalent to mentors providing constructive feedback to help and support mentees' growth. *Upward and downward information sharing* emphasizes leaders structuring and sharing relevant information with others promptly. Sharing relevant information without withholding is part of giving feedback. *Team player* and *Behavioral flexibility* demonstrate leaders being cooperative, and adaptive at work, while acknowledging style differences between of team members and adjusting their style to accommodate others. These two competencies match the last two components accounting for and adapting different communication styles in the mentoring competency *Communicate effectively*.

Mentors need to recognize their *influence as role models* to their mentees in a mentoring relationship. They should demonstrate: 1) striving for continuous growth, 2) taking initiation in work-related situations, 3) being honest to people, 4) conducting morally correct behavior, 5) persevering through adversities, and 6) taking responsibility for their own mistakes. These six aspects match the leadership competencies of *Self-development, Taking initiative, Honesty & Integrity, Perseverance,* and *Accountability* (Hiller et al., 2016).

The Unique Case of Delivering Result

One leadership meta-competency could not be matched with any mentoring competencies listed in the NASEM report. Scandura and Williams (2004) argued that leadership centers on people's performance while mentoring attunes to people's development, which could account for this lack of a match for the leadership meta competency, *Delivering results*. This leadership competency presents a unique case for the specific study undertaken. *Delivering results* emphasizes organizational operations and people's performance in accomplishing tasks, which is not part of the three main functions of mentoring (Scandura & Viator, 1994). ERC summer program mentoring contains a unique component focusing on mentee performance and project results that provide a potential match with such a competency. ERC summer program mentors' job responsibilities include supervising and managing their mentees' specific project progress and success. This extra project management-oriented component separates ERC summer program mentoring from other mentoring experiences and introduces the possibility of leadership meta competency, *Delivering results*, to reveal itself in this study of mentorship.

Summary

The two presented frameworks set the theoretical stage for this dissertation study to explore leadership understandings and competencies. The frameworks provide lens to examine the relatedness between mentoring experience and leadership development among engineering graduate students and postdoctoral scholars, which has been hinted at by a small number of existing studies (Kim, 2007; Dolan & Johnson, 2009; Walters &

Kanak 2016; Hayward et al., 2017; Zhao & Carberry, 2018; Limeri et al., 2019). The comparison between leadership competencies and mentoring competencies revealed a matching relationship between leadership and mentoring. The matching relationship provided directions for me to understand how being a mentor can help mentors' leadership development.

The dissertation primarily emphasizes the use of leadership competencies through a qualitative and quantitative study. The qualitative study leveraged the framework to analyze the development of leadership understanding and competencies by categorizing the leadership competencies reflected by ERC mentors. The quantitative study referenced the frameworks to develop instrument items to measure engineering graduate students and postdoctoral scholars' leadership understandings and competencies.

CHAPTER 5

QUALITATIVE STUDY

This dissertation uses a sequential exploratory design approach (Creswell & Clark, 2007) containing both a qualitative study and a quantitative study. The qualitative study (Phase I) explores an understudied area of understanding how serving as mentors affect leadership development among ERC engineering graduate student and postdoctoral scholars. The study did not compare the differences between ERC graduate students and postdoctoral scholars because those serving as postdoctoral scholars within an ERC also engaged in an ERC as graduate students, i.e., no participants only engaged in the ERC as a postdoctoral scholar. All study participants started their graduate program study and served as a summer program mentor in an ERC.

Research Questions

The qualitative study has two research questions.

RQ1: What are ERC engineering graduate student and postdoctoral scholar mentors' understanding of leadership?

RQ2: What part of leadership development do ERC graduate students and postdoctoral scholars experience through serving as summer program mentors?

Interview Protocol

A semi-structured phenomenological approach was taken to help answer the research questions using ERC graduate student and postdoctoral scholar mentors'

experiences and perceptions. Table 4 provides a list of the interview questions used to guide the interview. These questions aimed to engage participants in a reflection of their own perceptions and experiences regarding: 1) understanding of leadership, and 2) evolution of leadership understandings and competencies while mentoring others. The interview protocol was developed to motivate and encourage participants to reflect on their own experiences.

Table 4.

Semi-Structured Phenomenological Interview Questions

1.	What is your understanding of leadership?
2.	What is your understanding of mentorship?
3.	Please share with me what you did when you mentored in the [ERC] program (ERC was replaced by the specific ERC name during the interview).
4.	What are the top three things you learned from your experience as a mentor?
5.	In your opinion, does or does not your mentoring experience relate to your understanding of leadership and why?
6.	In your opinion, does or does not your mentoring experience relate to your leadership ability and why?
7.	Thank you for filling out the screening survey. You reported yourself applying leadership in daily work … Please comment or elaborate on your answer.

The interview protocol was piloted with a graduate student from a leadership program and an ERC graduate student. Feedback received and incorporated in the final version were centered around rewording the questions. One suggestion made was to clearly state the expectation of top three lessons learned from the mentoring experiences, instead of simply asking for lessons learned. The student believed a more structured and expectation-clarified question would reduce the overwhelming feeling that the open-ended questions might elicit from participants. Clarifying the number of expected lessons learned would also prevent someone to talk about one topic for too long. A second recommendation was to alter potentially directional words in the questions. One example

was to start question 4 with “does or does not” instead of just “does” to avoid question bias. One final recommendation was to use neutral verbs like “relate to” instead of cause-and-effect type verbs like “affect” or “impact” when asking the participants about their perceived relationship between a mentoring experience and leadership understanding. Verbs like “affect” or “impact” assume a causal relationship between the participants perceived relationship between their mentoring experience and leadership understanding, which could risk the participant feeling like the interviewer is phishing for answers.

Participant Recruitment and Data Collection

Former ERC mentors who had already started professional careers were recruited to participate in the qualitative study as they represented individuals who have experience in both mentoring and selecting a career pathway(s). Education directors, workforce development directors, and/or program evaluators from fourteen then-active ERCs who were at least three years old were contacted and asked to disseminate the study’s invitation letter to their ERC alumni. Four ERCs founded in the year 2020 were excluded from recruiting due to the low likelihood of having alumni.

A total of 26 alumni from seven different ERCs responded to the study invitation and expressed a willingness to participate. A screening survey was then sent out to gather background information, such as their ERC affiliated institution, academic standing while serving as a mentor for the ERC, type of summer programs mentored for the ERC, how many times they served as a mentor, current career field, and frequency of leading in their current profession. A subset of 21 initial volunteers filled out the screening survey; 17 former graduate students and postdoctoral scholar mentors from six different ERCs

across 11 different institutions were purposefully chosen to participate in the interview. The selection criteria used aimed to cover the widest variety of participants' background based on the responses to the screening survey (see Table 5 for details). Three out of four volunteers who were not selected to participate in the interview were all from the same ERC. Each did not diversify the sample regarding ERC, mentoring experience, career pathway and leadership experiences in daily job. Semi-structured phenomenological interviews were conducted with each participant via the Zoom videoconferencing tool. The length of the interviews varied between 40 and 60 minutes. All interviews were video recorded except one where the participant requested audio-only.

Table 5.

Interview Participants' Mentoring Experiences, Leadership Experiences, and Current Career Fields.

Participant	Mentored programs*	Number of mentees	Career fields	Frequency to lead in daily work
1	REU	1	Government	Sometimes
2	REU	1	Government	Always
3	REU, RET	3	Higher Ed/Faculty	Always
4	REU, RET	2	Higher Ed/Faculty	Most of the time
5	REU, RET, YSP	29	Higher Ed/ Postdoc	About half of the time
6	REU, RET	4	Higher Ed/ Postdoc, Entrepreneur	Sometimes
7	REU	2	Higher Ed/ Postdoc, Entrepreneur	Most of the time
8	RET	1	Higher Ed/Staff	About half of the time
9	REU, RET, YSP	13	Industry	Most of the time
10	REU	2	Industry	Most of the time
11	REU	2	Industry	About half of the time
12	YSP	1	Industry	About half of the time
13	REU, RET, YSP	5	National Lab	Sometimes
14	RET	3	National Lab	Sometimes
15	REU	2	National Lab	Sometimes
16	REU	1	National Lab	About half of the time
17	REU	1	NGO	Always

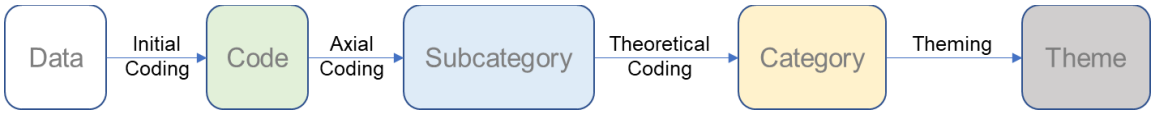
*REU – Research Experience for Undergraduates; RET – Research Experience for Teachers; YSP – Young Scholars Program

Data Analysis

A thematic analysis approach was used to analyze data collected for this exploratory study. Figure 1 demonstrates the qualitative data analysis procedures.

Figure 1.

Qualitative Data Analysis Procedure



The constant comparative method (Glaser, 1965) was applied to guide the coding process. A single coder (dissertation's author) first coded four interviews using the initial coding method (also referred to as open coding in certain literature) (Saldaña, 2016, p.115), as all content within the interviews was open for exploration. Codes were compared over all four interviews and similar codes were grouped into new codes. Initial codes were used to form the initial code structure. This approach kept the richest information and all the distinctions among the codes. A fifth interview was then coded independently by the first coder and a second coder. Each coder referenced the initial codebook to offer a second coding perspective. New emergent codes were compared with the initial codes and integrated into the codebook after the two coders reached a consensus on their codes for the fifth interview. The first coder then coded ten more interviews using the modified codebook. New emergent codes were iteratively compared to the existing codes and integrated into the codebook using the same approach mentioned previously. The first and second coders again coded another interview independently to examine inter-rater reliability. Data saturation occurred following the co-coding of the sixteenth interview when no new codes emerged. The first coder then

coded the final interview using the established codebook to verify that data saturation was reached. Initial codes were updated constantly for fit, relevance, and workability. All 17 interviews were examined and coded directly over the media files instead of transcripts. Direct coding of the video media allowed the coders to visually capture participants' non-verbal responses to the interview questions. Analytic memos (Saldaña, 2016, p.62) were also created throughout the coding process to document analyses of participants' nonverbal communication as a mechanism for personal reflection on the coding practices.

Inductive approaches were implemented during the coding process. The axial coding method (Saldaña, 2016) was applied to initial codes to further group them into conceptual subcategories referencing the conceptual framework. The theoretical coding method (Saldaña, 2016) was then adopted to put all the subcategory codes into higher-level categories, which were then labeled with key phrases. These key phrases built connections between the formulated codes and the research questions. They were also leveraged to develop themes to answer the research questions.

Findings

The qualitative study results suggest that ERC graduate students and postdoctoral scholars experienced both advancing leadership understanding and increasing competencies while serving as summer research project mentors. ERC graduate student mentors also reflected a "leader-centered" (Simmons et al., 2017) perspective in understanding leadership. The following subsections break down the results pertaining to each research question.

Understanding of Leadership

Only five participants were able to promptly describe their understanding of leadership. The remaining participants were not immediately prepared to answer this question. The interview videos captured the silent moments and surprised facial expressions when these participants heard the question. Many expressed the need to take some time to think about their response before answering. They responded with a laugh or smile while responding with quotes such as, “wow, that [question] is deep, let me think of it,” “I never thought about it until now,” and “I don't have an answer right now, I knew it is there but I just can’t organize [the pieces]”.

All 17 participants ultimately managed to respond to the question, with needing further prepping, chatting, or thinking time. Their perceptions all reflected a “leader-centered view” of leadership (Simmons et al., 2017), which equated leadership to who leaders are and what leaders do or shall do. The “relationship-centered,” “culture-centered” (Simmons et al., 2017), or “social process” (Chemers, 2014) views of leadership did not appear in any participants’ initial responses when asked to describe how they understand leadership. Sample quotes from participants identified who leaders were: “my boss was a really good leader; I learned a lot from her,” and “when talking about leadership, I think of Elon Musk.” Example quotes focusing on what leaders should do included statements like, “leaders lead by example,” “leaders make a team work [toward] the common goal,” “leaders apply communication skills,” and “[leaders] get things done.” Nine participants also mentioned leadership as an interpersonal relationship during the interview after being guided to compare mentoring and leadership.

The overall findings indicated that ERC graduate student mentors did gain awareness of leadership being a relationship. Such awareness was not strong enough to overcome their underlying leader-centered view on leadership or they lacked guidance or opportunities to reflect on their understanding of leadership prior to this interview.

Leadership Understanding Development

About half of the participants reported how their understanding of leadership evolved through mentoring others in ERC summer programs. These developments included discovering the humanitarian side of leadership, realizing the importance of teamwork, embracing a new role, fostering a new leadership style, and reflecting on followership. The most common change described was an increased awareness of empathy. Five participants described a new humanitarian view of leadership in recognizing that leadership requires empathy (e.g., "leaders need [to be] empathetic and personable" or "people want to [work] with empathic leaders"). One participant went as far as to say that mentoring others inspired him to start to "think [about] leadership on a meta-level, to figure out how to incite and motivate others to work." Another participant reflected that she started to focus more on team development in leadership following her mentoring experience. She spoke to leadership as "delegate[ing] appropriate tasks to the team and build[ing the] team's confidence" instead of being "a power figure [who is] heavy-handed and doing everything." Two other participants' understanding took yet another path in that they discovered "leadership involves teaching and developing others." One participant specifically described his teaching/development-esque leadership style as "offer[ing] resources, leveling up the team around me." He was not alone in this

perspective, as another participant fostered a similar service-focused perception that leadership is “service, connecting to people” by mentoring other people. Finally, the experience of mentoring and interacting with multiple mentees took one participant one step further in their development of leadership understanding. His reflection led them toward the importance of followership and always checking to “make sure [to] finish my part to help the leader” in his own work-life ever since. Serving as an ERC summer program mentor did provide opportunities for ERC graduate student mentors to grow how they view and understand leadership. The growth is very personalized compared to their leadership skill development.

Leadership Competency Development

Participants perceived serving as a mentor resulting in practicing leadership competencies. All participants believed that serving as an ERC summer program mentor helped them develop various leadership competencies, such as project management, communication, leading other people, and establishing shared visions. The excerpts from participants and their associated leadership competencies are presented in Table 6.

Managing mentees’ projects contributed to the development of mentors' project management competencies. ERC summer program mentors assist mentees in establishing project goals, breaking down tasks, planning a timeline, obtaining resources, monitoring progress, providing feedback, and organizing people’s work and time to generate quality research work. These experiences developed mentors’ leadership meta-competency in *Delivering results* (Hiller et al., 2016).

ERC graduate student mentors reported improved competencies of leading other people by learning how to effectively clarify roles and tasks with mentees, developing mentees' technical knowledge and engineering skills, motivating mentees to contribute, encouraging mentees to embrace work independence, and rewarding good work or behaviors. Such competencies of leading exhibit the leadership meta-competency of *Leading others* (Hiller et al., 2016).

Mentors developed communication competencies such as listening, respecting people's different opinions, and knowing how to address a different audience. Serving as mentors allowed the mentors to realize the importance of being supportive, present, approachable, relatable, flexible, and trustworthy for building interpersonal relationships inside and outside the work environment. Communication competencies are part of the leadership meta-competency of *Connecting with others* (Hiller et al., 2016).

Participants believed they gained the awareness to have a shared vision within the team. Everyone's buy-in on the vision is key for team success. The awareness was fostered through mentoring others because mentors experience a similar situation with mentees. Mentors need to ensure that their expectations from the mentoring relationship align with mentees'; otherwise, a healthy and fruitful mentoring relationship would be hard to achieve between the mentors and mentees. The desire to establish a shared vision for the team is part of the leadership meta competency *Providing strategic focus* (Hiller et al., 2016).

Table 6.

Participants' Excerpts in Leadership Competency Development through Serving as an ERC Summer Program Mentor

Leadership competencies	Participants' excerpts
Delivering results	"…make sure mentees know the [project] goals." "…make detailed [project work] plans & schedules for mentees." "…break down the [project] and assign tasks to mentees." "…manage mentee's workload." "…demonstrate how to do experiments."
Leading others	"..you need to let them know what they should do, what their tasks are…" "You can't just hand over a bunch of papers [to the interns] and hope they will read them and learn everything. You have to get them where they can do those things…" "I am OK to work with you when you need, but you have to learn how to do things independently." "You have to let them know when they did a good job."
Connecting with others	"I learned to listen." "I encourage[d] people to speak up [when they do not agree with me]…" "[People all] have their way to communicate and learn. I [as a leader] need to adjust [my communication styles] according to what they want." "[I became much better at] explaining technical stuff to people who do not know a thing [about the area]."
Providing Strategic results	"[You have to] make sure all team members have the same vision while [you] leading a team." "[Mentors need to] make sure you want the same outcomes out of the mentoring [relationship] as mentees do"

Summary

Overall, the majority of participants struggled to promptly describe leadership. Each was eventually able to do so, with all participants describing leadership using a leader-centered view of leadership. The relationship-centered, culture-centered, and social process views of leadership did not appear. Participants generally reported that their understanding of leadership evolved through their mentoring experience. They reported the belief that serving as a mentor resulted in an opportunity to practice leadership competencies. This suggests that such opportunities provide an interesting

mechanism to garner leadership understanding, but critical changes in how leadership is framed before engaging in the experience should be made to shift the view of leadership away from a leader-centered view.

CHAPTER 6

QUANTITATIVE STUDY

The Phase I qualitative study revealed that serving as a mentor in ERC summer programs provided opportunities and experiences for engineering graduate students and postdoctoral scholars to evolve their leadership understanding and advance their leadership competencies. A subsequent quantitative study (Phase II) was designed to investigate to what extent such findings hold and to further investigate the influence of serving as a mentor in ERC summer programs on leadership development and understanding among engineering graduate students and postdoctoral scholars. The Phase II study focused on the aspects of understanding and competencies regarding leadership development, in alignment with the Phase I qualitative study.

Research Questions

The quantitative study focused on a single research question:

RQ3: To what extent does serving as an ERC summer program mentor help engineering graduate students and postdoctoral scholars in developing leadership understanding and competencies?

The corresponding hypothesis for the research question is that serving as an ERC summer program mentor helps engineering graduate students and postdoctoral scholars develop leadership understanding by gaining awareness of empathy, embracing the role of leading and teaching, and learning leadership competencies relating to project management, effective communication, leading others, and creating a shared vision.

Instrument Development

An instrument was developed to facilitate the quantitative study. This instrument was developed by leveraging the qualitative study findings and existing literature. The instrument consisted of two components: leadership competencies and leadership understandings.

The survey was piloted with four participants before dissemination. The four pilot study participants included two former ERC graduate students and two engineering education researchers, with one specializing in engineering leadership and another specializing in quantitative research methods. This combination of pilot participants provided a comprehensive set of expert perspectives, including ERC experiences, engineering leadership, and instrument development. All three dissertation committee members reviewed the survey as well, providing additional content expertise. Their research expertise included leadership, instrument development, and mixed-methods research.

Leadership Competencies

Qualitative study participants described various improvements in leadership competencies, such as project management, communication, organization, and leading. The established instrument instantiated leadership competency items to test and explore the extent to which serving as an ERC summer program mentor improved graduate students and postdoctoral scholars' leadership competencies. Literature referenced to guide the leadership competency item development included the LCB (Hiller et al., 2016) and Engineering Leadership, Change, and Synthesis instrument (Ahn et al., 2014). The LCB

(Hiller et al., 2016) formed the conceptual framework for this dissertation and also provided a theoretical foundation for establishing both the constructs and the items. The Engineering Leadership, Change, and Synthesis instrument (Ahn et al., 2014) was referenced to offer an engineering contextual lens for the new instrument.

Table 7.

Leadership Competency Constructs and items

Construct 1: Leading Self
1. Learning new skills throughout your career.
2. Taking on responsibilities that are not assigned to you.
3. Seeking out leadership opportunities.
4. Taking responsibility for the actions of people who report to you.
5. Acknowledging when you are wrong.
Construct 2: Providing Strategic Focus
6. Providing creative ideas to solve problems.
7. Creating a shared vision for the group of people you work with.
8. Forming a group to accomplish a common goal.
9. Solving conflicts that arise within a group.
10. Considering the financial, social, and environmental consequences of your decisions.
Construct 3: Connecting with Others
11. Displaying empathy toward other people.
12. Treating other people with respect.
13. Listening to others' opinions even if they differ from your own.
14. Looking for opportunities to share your knowledge with others.
15. Explaining technical matters to people who are not familiar with your discipline.
Construct 4: Leading Others
16. Motivating others to accomplish predefined goals.
17. Encouraging others to take ownership of their work.
18. Creating a work environment in which people feel involved.
19. Helping people work through issues when they are stuck.
20. Facilitating developmental opportunities for others.
21. Praising others' achievements.
22. Adjusting how you interact with others based on their reactions.
Construct 5: Delivering Results
23. Setting clear goals for a group project.
24. Planning tasks and resources for a group project.
25. Delegating tasks and authority for a group project.
26. Demonstrating technical expertise in work-related activities.
27. Staying current with new technologies in work-related fields.

The instrument included all five meta-competencies from the LCB (Hiller et al., 2016) as the constructs: *leading self, providing strategic focus, connecting with others, leading others,* and *delivering results*. Four of the five meta-competencies – *providing strategic focus, connecting with others, leading others,* and *delivering results* – emerged from the qualitative data. Each also appeared in the engineering leadership measurements within the Engineering Leadership, Change, and Synthesis instrument (Ahn et al., 2014).

The criterion for item development was that any item included in the instrument must be: 1) introduced in the LCB (Hiller at el., 2016) to demonstrate theoretical fit, and 2) appear in the Engineering Leadership, Change, and Synthesis instrument (Ahn et al., 2014) and/or Phase I qualitative findings to address engineering context fit. A set of 27 leadership competency items were developed (Table 7). Five items specifically reflected on the discoveries made during the Phase I exploratory qualitative study: 1) displaying empathy toward other people, 2) helping people work through issues when they are stuck, 3) praising others' achievements, 4) adjusting how you interact with others based on their reactions, and 5) planning tasks and resources for a group project. These five items covered four aspects of changes in ERC graduate student and postdoctoral scholar mentors' leadership development: gaining awareness of having empathy, embracing the role to develop/teach others, improving effective communication, and advancing project management skills. Items "helping people work through issues when they are stuck" and "praising others' achievements" both measured the aspect of embracing the role of developing others. The reason to break down this aspect into two items was because the two items measured different behaviors of developing others. The former aims to capture guiding people through obstacles, while the latter emphasizes rewarding people's great

performance. Both aspects are critical for developing others. Five items were modified solely based on the Engineering Leadership, Change, and Synthesis instrument (Ahn et al., 2014): forming a group to accomplish a common goal, solving conflicts that arise within a group, considering the financial, social, and environmental consequences of your decisions, creating a work environment in which people feel involved, and staying current with new technologies in work-related fields. The remaining 17 items appeared in both the Engineering Leadership, Change, and Synthesis instrument (Ahn et al., 2014) and Phase I study interviews. A 5-point sacle (1=not at all competent to 5=extremely competent) was used for the leadership competency items.

Leadership Understandings

The LID Model (Komives et al., 2009) was adopted to guide the development of items for leadership understanding. The qualitative study participants responded with a description of who leaders are and what leaders should do when developing leadership understandings. One common perception of who leaders are was that leaders are the people who hold a certain level of organizational position or title. This perception of leaders being in certain positions matches the view of leadership in stage three of the LID Model: *Leader Identified*. The culture of sharing views of the leadership (Simmons et al., 2017), which was missing among qualitative study participant responses, aligns with stage four of the LID model: *Leadership Differentiated*. The reported advanced leadership understanding from the qualitative study touched on stage five of the LID model: *Generativity*.

Table 8.

Leadership Understanding Items

LID Model Level 3
1. Leadership is a role that only people who hold certain positions can occupy.
2. Only people who hold leadership positions are leaders.
3. Leaders' job is to get the work done.
4. People not in leadership positions look to leaders for directions.
LID Model Level 4
5. Leadership is a social process.
6. All group members participate in leadership regardless of their positions.
7. Anyone can be a leader regardless of whether they hold a leadership position.
LID Model Level 5
8. Leaders' job is to serve other people.
9. Leaders' job is to develop others to become leaders.
10. Leaders' job is to sustain a team or organization.
11. Leadership is being open to learning from others
LID Model Level 6
12. Leadership involves lifelong self-development.
13. Leadership is working with others to accomplish changes from any place in the organization.
14. Leadership is being trustworthy to others in a group.
Extra View of Leadership – Social Influence or Group Property
15. Leadership is a group attribute.
16. Leadership emerges through social interactions among all group members.
17. All group members influence each other, whether intentionally or not.
18. Leadership is a skill or a combination of skills that an individual has.

Leadership understanding items were generated to reflect the different views of leadership in stages three to six of the LID model: positional role leadership view, shared leadership view, leadership interpersonal responsibility view, and broad meaning of leadership view. Stages one and two of the LID model were not included because they do not fit with the study population. The first two stages generally happen during a person's childhood and adolescence (Komives et al., 2009). An extra view of leadership being a social influence and group property was also added to the instrument to capture this aspect of the definition of leadership used in this dissertation study. A total of 18 items (Table 8)

were generated to describe the five different views of leadership. A 5-point sacle (1=strong disagree to 5=strong agree) was used for the leadership understanding items as well.

Participant Recruitment and Data Collection

The quantitative research question was investigated through a retrospective reflection survey conducted with ERC graduate students and postdoctoral scholar mentors and non-mentors. The survey asked the participants to rate their current level of leadership understanding and competencies and the perceived impact of their ERC involvement on their level of leadership understanding and competencies. Information about other ERC leadership experiences (e.g., ERC Student Leadership Council or project leader) and outside ERC leadership experiences (e.g., student club leadership team, manager at a company, or sports team captain) were also collected from participants to control the influence of leadership development from non-ERC summer program mentoring experience(s). Participants' level of leadership understanding and competencies, as well as their perceived impact of ERC involvement on their levels of leadership understanding and competencies, were compared over three participant groups: 1) ERC graduate students and postdoctoral scholars who have served as mentors in at least one of ERC summer programs, 2) ERC graduate students and postdoctoral scholars who have never served as ERC summer program mentors but have self-reported having had other experiences with leadership, and 3) ERC graduate students and postdoctoral scholars who have never served as ERC summer program mentors and self-reported having not participated in other types of the leadership experiences.

The recruitment pool included all current engineering graduate students and postdoctoral scholars engaged with 11 active and seven sunsetting ERCs, i.e., their funding from NSF had come to an end. The survey was disseminated via email using the online survey platform, Qualtrics. The author took three different approaches to reach the participants. The author first connected with the workforce development directors and education directors of all 18 ERCs and asked for help distribute the survey to their current engineering graduate students and postdoctoral scholars. The author presented the recruitment need of the study at the ERC all-hands meeting and then asked its student and postdoc leadership council (SPLC) to help disseminate the survey. A third approach was implemented in the late stage of participant recruitment after the first two approaches only resulted in a limited number of participants. The author directly wrote to faculty members from a select set of four ERCs and asked them to help by encouraging the graduate students and postdoctoral scholars (who work with them) to participate in the survey. The author was only able to reach out to the faculty members in a subset of the ERCs due to time limitations.

The survey took participants approximately 15-20 minutes to complete. A total of 96 participants responded to the survey, and 74 of those responses were deemed usable based on the minimum completion of a least one question. The 74 usable responses consisted of 67 graduate students and seven postdoctoral scholars across 12 different ERCs. Table 9 breaks down the demographic information of the study's sample.

Table 9.

Quantitative Study Participant Demographic Information 7 postdoc

Category	Options	Count (Percentage)
Mentor	Yes	30 (41%)
	No: Had Other Leadership Experience	21 (28%)
	No: Did Not Have Other Leadership Experience	23 (31%)
Ethnicity/Racial Identity	American Indian, Native American, or Alaska Native	2 (3%)
	Asian or Asian American	19 (26%)
	Black or African American	3 (4%)
	Hispanic, Latino, or Spanish Origin	16 (22%)
	Middle Eastern, North African, or Arab American	2 (3%)
	White or European American	29 (39%)
	Multi-Racial	5 (7%)
	Unknown	10 (14%)
Gender Identity	Female	28 (38%)
	Male	32 (43%)
	Cisgender	2 (3%)
	Unknown	12 (16%)
Years in ERC	1	14 (19%)
	2	25 (34%)
	3	10 (13%)
	4	14 (19%)
	5	9 (12%)
	6+	2 (3%)
First-Generation Student	Yes	19 (26%)
	No	53 (74%)
Serving Military or Veteran	Yes	3 (4%)
	No	71 (96%)
U.S. Citizen or Permanent Resident	Yes	27 (37%)
	No	47 (63%)
Disability	Yes	3 (4%)
	No	71 (96%)

Data Analysis

All analyses were conducted using SPSS Version 28. Little's MCAR test was conducted to investigate whether the missing data were missing completely at random. Exploratory Factor Analysis (EFA) was executed over the leadership competency items

to collect validity evidence for the instrument. The chosen factor extraction method was Principal Axis Factoring (PAF). Promax rotation with Kapa=4 was also selected to improve the EFA results as the factors were not perfectly vertical to each other (i.e, factors were correlated to each other). Parallel analysis was applied to determine the number of factors to extract. The factor loading and cross-loading cutoff were set at 0.4 and 0.3, respectively (McCoach et al., 2013). Items with cross-loadings were deleted from the EFA results.

Items associated with only three leadership competency constructs were used during EFA since it is generally accepted that a sample size of at least five data points per item is sufficient for EFA and the sum total of 74 responses is proportionate to about 15 items. The three constructs selected were *Providing strategic focus, Leading others, and Delivering results*. All three constructs emerged as the improved leadership competencies for ERC summer program mentors in the qualitative study findings. *Leading others* matched the four mentoring competencies in the conceptual framework. *Delivering results* separates ERC summer program mentoring from other mentoring experiences that do not have a supervisory component. ERC summer program mentors' responsibility lacks the practice of *Providing strategic focus* compared to other types of leadership experience.

Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity were adopted to measure how suited the data was for EFA. KMO looks at the level of correlation between items. A high KMO value (KMO > 0.8) shows a strong partial correlation among items and, in turn, a high-level suitability for EFA (McCoach et al., 2013). Bartlett's test evaluates the null hypothesis that the correlation matrix of the items is an identity matrix,

i.e., all items are uncorrelated and cannot be factored. A significant level of the test ($p < 0.05$) rejects the null hypothesis and indicates that the items are correlated.

Cronbach's alpha was determined to provide a measure of internal consistency reliability. An alpha value measures how closely related a set of items are as a group. A high value of Cronbach's alpha (> 0.8) means all items loaded under a factor are closely related which represents a high level of scale reliability for that factor (McCoach et al., 2013).

Multiple One-way Analysis of Variance (ANOVA) tests were applied over each leadership competency and leadership understanding item to examine any potential significant mean differences among the three comparison groups: ERC mentors, ERC non-mentors who had other leadership experiences, and ERC non-mentors who did not have other leadership experiences. Bonferroni post hoc test were also conducted to examine the exact mean difference between each group pair when a significant mean difference was identified for any leadership competency and understanding item among the three comparison groups. The significant level was set at 0.05 ,which is a standard practice in engineering education quantitative study.

Results

Exploratory Factor Analysis (EFA)

Little's MCAR test indicated that the data were missing completely at random ($p > 0.05$). Group mean imputation (imputed the missing cell with the mean of the comparison group to whom the participant belongs: ERC mentors, ERC non-mentors who had other leadership experiences, and ERC non-mentors who did not have other

leadership experiences) was applied to handle the missing data due to the relatively high missing data rate (7.9% > 5%). EFA returned a three-factor structure (Table 10) . A high KMO value and a significant level for Bartlett's test indicated the strong factoring capability of the items (KMO = 0.85, Bartlett's test $p<0.001$) (McCoach et al., 2013). The factor structures obtained through EFA aligned with the conceptual framework. The three factors were named after the corresponding leadership meta-competency constructs: *Providing strategic focus, Leading others, and Delivering results*. Factors "Leading others" and "Delivering Results" achieved Cronbach's alpha values of 0.88 and 0.84, respectively. Factor "Providing Strategic Focus" obtained a significant Spearman's correlation 0.666. Eisinga et al (2003) argued spearman's correlation, instead of Cronbach's alpha, should reported as the reliability evidence for two-item factor. All three factors have good to moderate reliability of the leadership competency.

Table 10.

EFA Results in Leadership Competency Items

Competency Items	Factor		
	Leading others	Delivering Results	Providing strategic focus
Creating a shared vision for the group of people			0.87
Forming a group to accomplish a common goal.			0.69
Encouraging others to take ownership of their work.	0.83		
Creating a work environment in which people feel involved.	0.78		
Helping people work through issues when they are stuck.	0.69		
Facilitating developmental opportunities for others.	0.69		
Praising others' achievements.	0.69		
Setting clear goals for a group project.		0.84	
Planning tasks and resources for a group project.		0.89	
Delegating tasks and authority for a group project.		0.53	

Analysis of Variance (ANOVA)

Table 11 presents the results of the ANOVA analyses that compared each of the leadership competency items retained from the EFA across the three comparison population groups: 1) ERC graduate students and postdoctoral scholars who have served as mentors in at least one of ERC summer programs, 2) ERC graduate students and postdoctoral scholars who have never served as ERC summer program mentors but have experiences with other leadership activities, and 3) ERC graduate students and postdoctoral scholars who have never served as ERC summer program mentors and have not participated in other types of leadership experiences. These three groups were labeled as M, NMWL, and NMWOL, respectively, in all quantitative results in this dissertation.

ERC graduate students and postdoctoral scholars who have served as summer program mentors (M) reported a significantly higher level of competency in "helping people work through issues when they are stuck" (mean difference = 0.6, $p = 0.02$), "facilitating development opportunities for others" (mean difference = 0.76, $p = 0.01$), and "delegating tasks and authority for a group project" (mean difference = 0.65, $p = 0.01$) compared to their peers who have never served as summer program mentors nor have other leadership experiences (NMWOL). All three significant mean differences had a medium to large effect size ($f > 0.3$), suggesting the results are meaningful.

Though not significantly different, ERC summer program mentors (M) also scored a higher mean on average for every other competency item than their non-mentor peers who had no other leadership experiences (NMWOL). These results suggest that the experience of serving as a mentor in an ERC summer program may have helped ERC graduate students and postdoctoral scholars develop certain leadership competencies.

Similar significant mean differences did not appear between the ERC summer program mentors (M) and their peers who have not served as mentors but have other leadership experiences (NMWL).

Table 11.

ANOVA Results on Participants' Current Level of Leadership Competencies across Three Comparison Population Groups

Factor	Competence	Omni Sig.	Mean			Mean Difference			Effect Size: f
			NM WOL	NM WL	M	NM WOL-NM WL	NM WOL-M	NM WL-M	
Providing strategic focus	Creating a shared vision for the group of people y	0.16	3.50	3.86	3.9	-0.36	-0.40	-0.04	0.24
	Forming a group to accomplish a common goal.	0.18	3.46	3.62	3.9	-0.16	-0.44	-0.28	0.21
Leading others	Encouraging others to take ownership of their work.	0.06	3.38	3.86	3.97	-0.48	-0.59	-0.11	0.26
	Creating a work environment in which people feel involved.	0.21	3.71	4.1	4.07	-0.39	-0.36	0.03	0.19
	Helping people work through issues when they are stuck.	0.02	3.5	3.95	4.1	-0.45	-0.6*	-0.15	0.31
	Facilitating developmental opportunities for others.	0.01	3.21	3.76	3.97	-0.55	-0.76*	-0.21	0.34
	Praising others' achievements.	0.19	3.96	4.33	4.23	-0.38	-0.28	0.1	0.22
Delivering results	Setting clear goals for a group project.	0.23	3.71	3.95	4.1	-0.24	-0.39	-0.15	0.21
	Planning tasks and resources for a group project.	0.13	3.75	4.14	4.17	-0.39	-0.42	-0.02	0.24
	Delegating tasks and authority for a group project.	0.01	3.58	3.76	4.23	-0.18	-0.65*	-0.47	0.37

M – Mentors; NMWOL – non-mentors without other leadership experience; NMWL: non-mentors with other leadership experience

* p-value <0.05

Table 12 shows the ANOVA results over the leadership understanding items across the three comparison population groups. Leadership understanding items measured levels, rather than different aspects or dimensions of understanding on leadership. The leadership understanding levels are not mutually exclusive. A certain level of correlation can be expected between items across different levels, especially among LID model level

4, 5, 6 and the extra items added. A factor analysis was therefore not conducted over leadership understanding items. ERC graduate and postdoctoral summer program mentors agreed with the statement, “leadership is being open to learning from others,” significantly more than their peers who had never served as mentors in summer programs nor have other leadership experiences (M vs. NMWOL, mean difference = 0.55, $p = 0.02$). This result suggests that serving as an ERC mentor may help graduate students and postdoctoral scholars become more open to learning from others to achieve group success. ERC summer program mentors also agreed with the statement, “leadership is a group attribute,” significantly less than their peers who had not served as mentors but had other leadership experiences (M vs. NMWL, mean difference = -0.76, $p = 0.03$). This result suggests that ERC mentors were less likely to see leadership as a group attribute than as an individual attribute relative to their peers with other leadership experiences. This difference could indicate that ERC summer program mentoring opportunities have shortcomings in the understandings of leadership that participants develop compared to other leadership experiences.

Table 12.

ANOVA Results on Participants' Current Level of Leadership Understanding across three Comparison Population Groups

LID Model Level	Understanding	Sig.	Mean			Mean Difference			Effect Size: f
			NM WOL	NM WL	M	NM WOL-NM WL	NM WOL-M	NM WL-M	
3	Leadership is a role that only people who hold certain positions can occupy.	0.55	1.95	1.76	2.15	0.19	-0.20	-0.37	0.14
	Only people who hold leadership positions are leaders.	0.70	1.8	1.52	1.74	0.28	0.06	-0.22	0.11
	Leader's job is to get the work done.	0.34	2.85	2.29	2.67	0.56	0.18	-0.38	0.18
	People not in leadership positions look to leaders for directions.	0.54	3.65	3.38	3.74	0.27	-0.09	-0.36	0.14
4	Leadership is a social process.	0.49	4.05	4.29	4.30	-0.24	-0.25	-0.01	0.15
	All group members participate in leadership regardless of their positions.	0.44	3.75	3.95	3.56	-0.20	0.19	0.40	0.16
	Anyone can be a leader regardless of whether they hold a leadership position.	0.59	4.25	4.48	4.48	-0.23	-0.23	-0.01	0.13
5	Leaders' job is to serve other people.	0.30	3.7	4.05	4.19	-0.35	-0.49	-0.14	0.19
	Leaders' job is to develop others to also become leaders.	0.32	3.85	4.10	4.26	-0.25	-0.41	-0.16	0.19
	Leaders' job is to sustain a team or organization.	0.08	4.15	4.38	4.63	-0.23	-0.48	-0.25	0.28
	Leadership is being open to learning from others	0.02	4.3	4.52	4.85	-0.22	-0.55*	-0.32	0.36
6	Leadership involves lifelong self-development.	0.34	4.55	4.57	4.78	-0.02	-0.23	-0.21	0.18
	Leadership is working with others to accomplish changes from any place in the organization.	0.14	4.2	4.48	4.63	-0.28	-0.43	-0.15	0.25
	Leadership is being trustworthy to others in a group.	0.54	4.5	4.7	4.59	-0.20	-0.09	0.11	0.14
Extra	Leadership is a group attribute.	0.03	4.05	4.43	3.67	-0.38	0.38	0.76*	0.34
	Leadership emerges through social interactions among all group members.	0.38	4.2	4.48	4.44	-0.28	-0.24	0.03	0.18
	All group members influence each other through the course of leadership, whether intentionally or not.	0.06	3.95	4.52	4.44	-0.57	-0.49	0.08	0.30
	Leadership is a skill or a combination of skills that an individual has.	0.09	4.05	4.38	4.56	-0.33	-0.51	-0.17	0.28

M – Mentors; NMWOL – non-mentors without other leadership experience; NMWL: non-mentors with other leadership experience

* p-value <0.05

No significant mean differences were detected in participants' perceived ERC impact on leadership competencies and understanding development among all three participant groups (Tables 13 and 14). All ERC graduate students and postdoctoral scholars, regardless of mentoring or leadership experiences, perceived the equivalent level of impact of their involvement on the development of their leadership competencies and understanding.

Table 13.

ANOVA Results on ERC Impact on Participants' Level of Leadership Competencies across Three Comparison Population Groups

ERC impact on competence	Omni Sig.	Mean			Mean Difference		
		NM WOL	NM WL	M	NM WOL-NM WL	NM WOL-M	NM WL-M
Creating a shared vision for the group of people you work with.	0.43	3.45	3.76	3.82	-0.31	-0.37	-0.06
Forming a group to accomplish a common goal.	0.11	3.29	3.90	3.79	-0.62	-0.5	0.12
Encouraging others to take ownership of their work.	0.64	3.10	3.25	3.39	-0.15	-0.30	-0.14
Creating a work environment in which people feel involved.	0.27	3.43	3.62	3.93	-0.19	-0.50	-0.31
Helping people work through issues when they are stuck.	0.57	3.43	3.48	3.71	-0.05	-0.29	-0.24
Facilitating developmental opportunities for others.	0.14	3.19	3.62	3.86	-0.43	-0.67	-0.24
Praising others' achievements.	0.72	3.57	3.76	3.79	-0.19	-0.21	-0.024
Setting clear goals for a group project.	0.65	3.24	3.43	3.54	-0.19	-0.30	-0.11
Planning tasks and resources for a group project.	0.7	3.29	3.52	3.54	-0.24	-0.25	-0.01
Delegating tasks and authority for a group project.	0.16	3.05	3.52	3.64	-0.47	-0.59	-0.12

M – Mentors; NMWOL – non-mentors without other leadership experience; NMWL: non-mentors with other leadership experience

Table 14.

ANOVA Results on ERC Impact on Participants' Level of Leadership Understanding across Three Comparison Population Groups

		Mean			Mean Difference		
ERC impact on understanding	Omni Sig.	NM WOL	NM WL	M	NM WOL-NM WL	NM WOL-M	NM WL-M
Leadership is a role that only people who hold certain positions can occupy.	0.46	2.75	3.30	3.04	-0.54	-0.29	0.25
Only people who hold leadership positions are leaders.	0.57	2.55	2.90	2.93	-0.35	-0.38	-0.02
Leader's job is to get the work done.	0.68	3.00	3.35	3.22	-0.33	-0.22	0.11
People not in leadership positions look to leaders for directions.	0.60	3.00	3.35	3.33	-0.33	-0.33	0.00
Leadership is a social process.	0.52	3.10	3.55	3.26	-0.42	-0.16	0.26
All group members participate in leadership regardless of their positions.	0.75	3.15	3.40	3.15	-0.23	0.00	0.23
Anyone can be a leader regardless of whether they hold a leadership position.	0.63	3.32	3.70	3.42	-0.35	-0.11	0.24
Leaders' job is to serve other people.	0.55	3.11	3.50	3.12	-0.37	-0.01	0.36
Leaders' job is to develop others to become leaders.	0.89	3.37	3.35	3.19	0.04	0.18	0.14
Leaders' job is to sustain a team or organization.	0.91	3.32	3.50	3.35	-0.16	-0.03	0.13
Leadership is being open to learning from others	0.45	3.16	3.65	3.23	-0.46	-0.07	0.39
Leadership involves lifelong self-development.	0.59	3.16	3.60	3.42	-0.41	-0.26	0.15
Leadership is working with others to accomplish changes from any place in the organization.	0.43	3.10	3.65	3.27	-0.52	-0.17	0.35
Leadership is being trustworthy to others in a group.	0.83	3.45	3.50	3.27	-0.03	0.18	0.21
Leadership is a group attribute.	0.43	3.11	3.60	3.15	-0.47	-0.05	0.42
Leadership emerges through social interactions among all group members.	0.60	3.15	3.55	3.27	-0.37	-0.12	0.25
All group members influence each other through the course of leadership, whether intentionally or not.	0.77	3.20	3.50	3.31	-0.28	-0.11	0.17
Leadership is a skill or a combination of skills that an individual has.	0.83	3.30	3.55	3.35	-0.22	-0.05	0.18

M – Mentors; NMWOL – non-mentors without other leadership experience; NMWL: non-mentors with other leadership experience

Summary

ERC mentors reported significantly higher competence in certain tasks related to developing others and managing projects and a significantly higher level of agreement on being open to learning from others compared to their ERC non-mentor colleagues who had no leadership experience. This quantitative result supports the findings from the

Phase I qualitative study that ERC mentoring experiences made positive impact in developing certain leadership competencies, like developing others and delivery project results.

No significant mean differences were found in any leadership competency item between ERC summer program mentors and ERC non-mentors with other leadership experiences. ERC mentors had a higher mean on all items except two; neither was reported at a significant level. The progress in leadership competence development made by serving as an ERC summer mentor could be at least equivalent or comparatively impactful to other leadership experiences.

CHAPTER 7

DISCUSSION

Qualitative study participants remarked that not everyone wants to be the leader or can be the leader. Some expressed frustration with the limited job choice options if they did not feel comfortable being a leader. This notion challenges their sense of belonging in the engineering workforce. One participant specifically mentioned not feeling comfortable at all in being a leader or taking on a leadership position. That participant did not know how to contribute their expertise in a group without facing a situation where everyone would be looking to them for leadership. That participant then chose a career pathway where they could complete all tasks alone and take no responsibility as a leader.

Leadership education is different from leader education. The traditional way of training everyone to be a leader does not fit engineering leadership education (Simmons et al., 2017; Schell & Hughes, 2022). Changes must happen. One way is to introduce and incorporate other views of leadership. A relational view of leadership (Schell & Hughes, 2022) and cultural view of leadership (Simmons et al., 2017) should be considered alternative candidates. The relational view of leadership states that leadership is a social process of influence, not an indicator of who is in charge (Schell & Hughes, 2022). The team-based view of leadership emphasized within the ABET student outcomes (ABET, 2019) similarly focuses on team building, sharing, collaboration, achievement, and support (Wolfinbarger, 2015). The cultural view of leadership describes leadership as influence, contribution, and participation, rather than organization and structure (Simmons et al., 2017). Engineering students and postdoctoral scholars could better

recognize that one does not need to be the leader all the time to contribute to leadership by shifting their understanding of what leadership is away from the leader-centric view. They could further develop the ability to decide when to be more active in managing a group and when to step back into following.

Mentoring Experience Itself is Not Enough

The qualitative study participants' reported leadership development focused on leadership competencies and ability level with very little discussion of leadership as a social interaction (e.g., Crevani et al. (2010) and Day et al. (2014).) These results indicate that mentoring experiences alone might not be enough for engineering graduate student mentors to adequately learn and develop new leadership understandings. Adults have a frame of beliefs, positions, and values and tend to resist changes to this frame unless explicitly challenged (Mezirow, 1997). ERC engineering graduate student mentors were asked to interpret, reflect on, and connect their mentoring experience to what they perceived as leadership. Their responses were situated within their understanding of leadership, which they expressed in terms of leadership positions and competencies. A small group of participants even expressed the complete absence of ever thinking of the concept of leadership or connecting their mentoring experience to leadership until the interview.

Leadership program organizers and engineering educators can initiate transformational learning around leadership by providing students with experiences that help recognize and test their leadership-related beliefs, positions, and values (Mezirow,1997). Instructional activities to introduce a clear relational or culture-laden

leadership definition alongside relevant topics are needed in engineering leadership education (not just ERC summer mentoring opportunities), which matches the first action step for future engineering leadership education suggested by Simmons et al. (2017). Schell and Hughes (2022) observed a shift to a more relational understanding of leadership among participants in their focus group interviews. Students recognized that effective leadership was achieved through a process of social influence and that a person's role or position on a team did not play an impactful role in this process. Schell and Hughes (2022) also recommended using formal reflection as a supplemental approach to developing a relational and/or cultural understanding of leadership among engineering students and postdoctoral scholars.

The positional understanding of leadership was not found in the quantitative study. All participants agreed with the items associated with a positional view of leadership much less than they did with the items associated with leadership being a social interaction or shared responsibility regardless of their prior mentoring and leadership experiences. These results may be skewed because quantitative study participants had the opportunity to see all the leadership understanding items at once, which may have broadened their views regarding leadership. One participant who helped pilot the instrument reflected that she would have never imagined leadership having so many layers of meaning prior to answering the survey questions. Qualitative interview participants, conversely, had no awareness of such information when responding to the interview questions. The quantitative survey itself could be considered a mini intervention related to leadership education.

The overall findings suggest that ERC summer mentoring programs provide one pathway toward leadership development for engineering graduate students and postdoctoral scholars. The studies suggest that ERCs need to put more effort into motivating their graduate students and postdoctoral scholars to participate in the programs. Interventions, knowledge, and curricular activities around the concept of leadership beyond just being a leader of others needs to be integrated into the programs to extend the impact in leadership development.

CHAPTER 8

FUTURE WORK

Immediate future work should focus on collecting more quantitative data to expand possible analyses. An increased sample size would benefit the EFA and ANOVA calculations presented in this dissertation. A larger sample size would make running the EFA on all five constructs (leading self, providing strategic focus, connecting to others, leading others, and delivering results) feasible while also increasing the power for ANOVA in mean comparison.

The next step would be to expand the study to investigate the impact of leadership development on engineering graduate student and postdoctoral scholars' career pathway selection. Many studies have explored the impact of leadership development on students' career readiness (Paul & Falls, 2015; Seemiller, 2018; Fox, 2018) and career decision-making self-efficacy (Schuh, 1983; Paulsen & Betz, 2004; Fox, 2018). Career pathway selection is yet understudied. Some work could be done in exploring whether leadership development experiences impact how engineering graduate students and postdoctoral scholars choose different career pathways.

Future research could also explore how certain leadership competencies were improved or advanced for graduate students and postdoctoral scholars through serving as a mentor. This dissertation study explored and examined what aspects of leadership understandings and leadership competencies were developed through serving as an ERC summer program mentor, which could provide a foundation to further explore the experiences of leadership development through the mentorship of others. Longitudinal

studies that track how leadership competencies and understanding are developed through mentoring experiences over time could be implemented.

The findings of this dissertation are limited to the NSF-funded ERC context. Further work should aim to address whether mentorship experiences lead to leadership development among engineering graduate students and postdoctoral scholars more broadly.

CHAPTER 9

POSITIONALITY AND LIMITATIONS

This dissertation was influenced by my own personal positionality and limitations associated with the chosen methods. I am a researcher who initially held a leader-centered view of leadership. My views on leadership shifted to a more robust social interaction-based view as I read the literature and analyzed data from this dissertation study. I believe that engineers would benefit from adopting a more relational and social view of leadership. This perspective was also held by those who contributed to data coding. These personal biases by those who engaged in this research could have resulted in the interviews focusing on a leader-centered understanding of leadership.

I built the conceptual framework by matching leadership competencies and mentoring competencies. Though the matching relationship was established by strictly analyzing and comparing the content of the competencies given by the literature, the work was still accomplished through a lens of my own personal understanding and experience. The framework could be influenced by my confirmatory bias as I see a strong connection between leadership competencies and mentoring competencies.

I am also heavily influenced by the framework I created, which I believe reflects how exactly leadership experiences connect to mentoring experiences. This positionality could have forced context that was purely speculative through my interpretation of the research data and findings. My committee members, especially the member who served as the second coder in the qualitative study, helped addressed this issue.

All studies also come with additional limitations tied to chosen research methods. The first methods limitation of this dissertation was choosing not to conduct member

checking with participants. The omission of member checks could lead to a misinterpretation of the interviewee's words, which in turn affects the accuracy and validity of the findings. The use of a second, independent coder during the coding process helped mitigate such a risk to a certain degree, but not all.

The second methods limitation was the small sample size collected for the quantitative study. Every effort was made to obtain a sample large enough to meet the requirements for the chosen quantitative analyses. The total population of graduate students and postdoctoral researchers in ERCs is limited to those who engage in these centers, which placed a limitation on who was eligible to complete the survey. Multiple mechanisms were used to connect with this population, including multiple reminder emails. A larger sample of this overall population will be needed to build on the results presented in this dissertation.

The third methods limitation was the design of the quantitative study. A retrospective approach was designed in this study, which asked participants to recall their experiences involved in ERC. Participants were asked to reflect back on how such experiences impacted their leadership development. The perception could be skewed by individuals' memory, especially for the individuals who have not been involved in the ERC for a long time period. Recalling a past experience and distinguishing its resulting impact on oneself from other personal experiences is a difficult task. Many factors could play into the reflection and skewing participants' recollections. A longitudinal study could overcome this obstacle.

CHAPTER 10

CONCLUSION

ERC engineering graduate students and postdoctoral scholars experienced development in both leadership understanding and competencies. Such development, in turn, influenced their plan and choice of career pathway. Advances in their leadership understanding included increased awareness of the importance of empathy, support, and people development. Improvements in their leadership competencies focused on project management, leading other people, communication, and establishing a shared vision for their team.

ERC summer program mentoring experiences could establish a great leadership development opportunity for engineering graduate students and postdoctoral scholars. Graham et al. (2009) revealed a few common issues among engineering leadership programs around the world: 1) lacking available resources, engineering faculty engagement, formal networks, and research programs, and 2) difficulty in identifying and finding adequate faculty and staff members to deliver effective programs (e.g., leadership programs lack of engineering faculty with expertise in leadership, and/or lack research programs focused on engineering leadership). ERCs have unique advantages that can address such issues, including resource to seek adequate faculty members to teach leadership content. Resource available to and from ERCs can also greatly benefit conducting engineering leadership research. This dissertation could not be accomplished without leveraging available ERC resources and network. An ERC can be funded by the National Science Foundation for a maximum of ten years, which provides rich resources, including a stable budget, extensive collaboration within multiple academic institutions,

diversified expertise from center-affiliated personnel, high-level engagement from engineering faculty members, active involvement in various research communities, wide connection with local K-12 and the local community, reputable long-term industry partners, and other various levels of support from NSF. Wide connections to community and industry partners made by ERCs can also provide service-learning opportunities for leadership development (Huff et al., 2016). ERC summer program mentoring experiences as opportunities for leadership development fits the concept of a "non-explicit" engineering leadership program defined by Graham et al. (2009), in which the engineering leadership development component is embedded within a broader context. ERCs should consider promoting leadership-developing mentoring experiences as a required part of every ERC-affiliated graduate student and postdoctoral scholar's academic journey.

Mentoring experience alone might not be enough for engineering graduate students and postdoctoral scholars to adequately learn and develop leadership. The reported leadership development that participants noted centers on particular competencies and the understanding that they will develop into good leaders. It's important to note that very little education about the concept of leadership being a social interaction (Crevani et al., 2010; Day et al., 2014) or team culture activity (Simmons et al., 2017) was reported. Rottmann and colleagues (2014) found that professional engineers did not consider leadership part of their identity even though they perform leadership behaviors in their daily work. They believed professional engineers have a misconception about leadership being a role, a title, or a position. This scenario indicates that professional engineers have the same "leader-centered" perception of leadership as

the participants in this study, which might explain the sources of engineering students' leader-centered understanding of leadership discovered in this dissertation being the education they received. Engineering students either lack leadership education or proper leadership education.

United States-based leadership programs tend to focus either on leadership "theory" or team projects, neither of which is a balanced and/or effective leadership development trajectory (Graham et al., 2009). The findings of this dissertation indicate that leadership development focused on the practice of mentoring alone is also not enough to develop an adequate, especially teamwork-centered, understanding of leadership. Effective leadership development also requires introducing appropriate leadership concepts, theory, knowledge, and thinking, perhaps through co-curricular offerings. ERCs have the unique advantage to combine and incorporate both leadership knowledge and practices into one program with wide involvement of leadership and education experts. Leveraging the already established mentoring opportunities offered by ERCs can allow such centers to be great venues to balance the theoretical and practical emphasis of leadership development programs and achieve more systemic results than current leadership program models.

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APPENDIX A

IRB APPROVAL FOR QUALITATIVE STUDY

ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Adam Carberry
IAFSE-PS: Polytechnic Engineering Programs (EGR)
480/727-5122
Adam.Carberry@asu.edu

Dear Adam Carberry:

On 11/23/2020 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Investigating the Impact of Engineering Students' Perceived Importance of Communication Skills on Engineering Career Choices
Investigator:	Adam Carberry
IRB ID:	STUDY00012959
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Dissertation_IRB_ZhenZhao.docx, Category: IRB Protocol; • Dissertation_Screening_Survey.pdf, Category: Screening forms; • Interview protocol.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Recruitment_letter.pdf, Category: Recruitment Materials; • Study Information and Consent letter.pdf, Category: Consent Form;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 11/23/2020.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

If any changes are made to the study, the IRB must be notified at research.integrity@asu.edu to determine if additional reviews/approvals are required. Changes may include but not limited to revisions to data collection, survey and/or interview questions, and vulnerable populations, etc.

Sincerely,

IRB Administrator

cc: Zhen Zhao
Zhen Zhao
Adam Carberry
Samantha Brunhaver
Jennifer Chandler

APPENDIX B
IRB APPROVAL FOR QUANTITATIVE STUDY

ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Adam Carberry
IAFSE-PS: Polytechnic Engineering Programs (EGR)
480/727-5122
Adam.Carberry@asu.edu

Dear Adam Carberry:

On 9/16/2022 the ASU IRB reviewed the following protocol:

Type of Review:	Modification / Update
Title:	Investigating the Impact of Engineering Students' Perceived Importance of Communication Skills on Engineering Career Choices
Investigator:	Adam Carberry
IRB ID:	STUDY00012959
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Consent Form, Category: Consent Form; • Dissertation IRB Modification, Category: IRB Protocol; • Gift Card Drawing Registration Form, Category: Other; • Invitation Letter, Category: Recruitment Materials; • Reminder Letter, Category: Recruitment Materials; • Study Instrument, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 9/16/2022.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

If any changes are made to the study, the IRB must be notified at research.integrity@asu.edu to determine if additional reviews/approvals are required. Changes may include but not limited to revisions to data collection, survey and/or interview questions, and vulnerable populations, etc.

REMINDER - - Effective January 12, 2022, in-person interactions with human subjects require adherence to all current policies for ASU faculty, staff, students and visitors. Up-to-date information regarding ASU's COVID-19 Management Strategy can be found here. IRB approval is related to the research activity involving human subjects, all other protocols related to COVID-19 management including face coverings, health checks, facility access, etc. are governed by current ASU policy.

Sincerely,

IRB Administrator

APPENDIX C
QUALITATIVE INTERVIEW PROTOCOL

Qualitative Interview Protocol

Study Title: Examining ERC Mentoring Experience' impact on Understanding of Leadership among Engineering Postdoctoral Scholars and Graduate Students

Thank you for allowing me to talk with you today. My name is Zhen Zhao and this is my dissertation study. I am interested in hearing about your experience as a mentor for XXX (will be replaced with the specific ERC name) summer programs, your understanding of leadership, and your career planning. The information you provide will be used to help improve the mentoring experience and better develop professional skills for XXX graduate students and postdoctoral scholars and will serve as the primary source of data for research publications.

This semi-structured interview session will consist of only open-formed questions. During this session, I am going to ask you some questions about your experiences in serving as a mentor for XXX summer programs, your understanding of leadership, and how you navigated your career planning.

This interview will last no longer than 60 minutes. This interview will be audio/video (depending on the participants 'preference) recorded, and the recording file will be sent to a professional agency for transcription. All data will be stored in a secured, ASU-owned cloud drive, and only be accessed by me and my dissertation committee members. Data collected from the study may be used in reports and/or publications. The information will remain confidential. Any published quotes will be anonymous. However, to protect your identity, please refrain from using names or other identifying information during the interview. Your participation in this interview is voluntary, and

you may choose to quit at any time. Let me know if, at any time, you do not want to be recorded and I will stop.

Before we begin, do you have any questions? Now, if you agree to participate in the interview, we will start recording.

{START AUDIO/VIDEO RECORDING}

Interview Questions

1. What is your understanding of leadership?
2. What is your understanding of mentorship?
3. Please share with me what you did when you mentored in the [ERC] program (ERC was replaced by the specific ERC name during the interview).
4. What are the top three things you learned from your experience as a mentor?
5. In your opinion, does or does not your mentoring experience relate to your understanding of leadership and why?
6. In your opinion, does or does not your mentoring experience relate to your leadership ability and why?
7. Thank you for filling out the screening survey. You reported yourself applying leadership in daily work … Please comment or elaborate on your answer.

Thank you very much for your time, I appreciate your honesty, patience, and openness. I am going to have the recording transcribed by a professional agency. I will reach out to you if I need further clarification or confirmation about today's conservation. Also, please let me know if you think of anything that I should know. Thank you, and have a great day.

{END AUDIO/VIDEO RECORDING}

APPENDIX D

QUANTITATIVE INSTRUMENT

Dissertation Quantitative Survey

Start of Block: ERC Affiliation_1

Q3 Section 1: Engineering Research Center (ERC) Affiliation

Q4 Please select with which Engineering Research Center (ERC) you are affiliated.

- ○ ASPIRE (Center for Advancing Sustainability through Powered Infrastructure for Roadway Electrification)
- ○ ATP-BIO (Center for Advanced Technologies for the Preservation of Biological Systems)
- ○ ASSIST (Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies)
- ○ CBBG (Center for Bio-mediated and Bio-inspired Geotechnics)
- ○ CELL-MET (Center for Cellular Metamaterials)
- ○ CISTAR (Center for Innovative and Strategic Transformation of Alkane Resources)
- ○ CMaT (Center for Cell Manufacturing Technologies)
- ○ CNT (Center for Neurotechnology)
- ○ CQN (Center for Quantum Networks)
- ○ CURENT (Center for Ultra-wide-area Resilient Electric Energy Transmission Network)
- ○ IoT4Ag (Center for the Internet of Things for Precision Agriculture)
- ○ NASCENT (Center for Nanomanufacturing Systems for Mobile Computing and Energy Technologies)
- ○ NEWT (Center for Nanotechnology-Enabled Water Treatment)
- ○ PATHS-UP (Center for Precise Advanced Technologies and Health Systems for Underserved Populations)
- ○ POETS (Center for Power Optimization for Electro-Thermal Systems)
- ○ QESST (Center for Quantum Energy and Sustainable Solar Technologies lab)
- ○ ReNUWIt (Center for Re-Inventing the Nation's Urban Water Infrastructure

○ TANMS (Center for Translational Applications of Nanoscale Multiferroic Systems)

○ Not listed above, please specify:
_____

End of Block: ERC Affiliation_1

Start of Block: ERC Affiliation_2

Q5 Select your role(s) in ${e://Field/ERC}. Please check all that apply.

☐ Graduate student

☐ Postdoctoral scholar

☐ Not listed, please specify:
_____

Q6 What is your field of study?

_____

Q7 How many years have you been involved with ${e://Field/ERC}?   This is my ____ year involved with the ${e://Field/ERC}.

- 1st
- 2nd
- 3rd
- 4th
- 5th
- 6+

Q8 Have you served as a mentor in any of the ${e://Field/ERC} summer programs (e.g., REM, RET, REU, REV, YSP)?

- Yes
- No
- Prefer not to answer

Q9 Please estimate, if you can, how many ${e://Field/ERC} summer program participants have you mentored?

- ○ 1
- ○ 2
- ○ 3-5
- ○ 6-9
- ○ 10-15
- ○ 15-20
- ○ 20+

Q10 Select the institution(s) primarily associated with your ${e://Field/ERC} role. Please check all that apply.

- [ ] Arizona State University
- [ ] Boston University
- [ ] Brigham Young University
- [ ] California Institute of Technology
- [ ] California State University, Northridge
- [ ] Colorado School of Mines
- [ ] Colorado State University
- [ ] Columbia University in the City of New York
- [ ] Cornell University
- [ ] Emory University
- [ ] Florida International University
- [ ] Georgia Institute of Technology
- [ ] Gladstone Institutes
- [ ] Harvard University
- [ ] Howard University
- [ ] Massachusetts General Hospital

- [ ] Massachusetts Institute of Technology
- [ ] Morehouse College
- [ ] Morgridge Institute for Research
- [ ] New Mexico State University
- [ ] North Carolina State University
- [ ] Northeastern University
- [ ] Northern Arizona University
- [ ] Northwestern University
- [ ] Pennsylvania State University
- [ ] Purdue University
- [ ] Rensselaer Polytechnic Institute
- [ ] Rice University
- [ ] San Diego State University
- [ ] Southwestern College
- [ ] Spelman College
- [ ] Stanford University
- [ ] Texas A&M University

- [ ] The University of Arizona
- [ ] The University of Auckland
- [ ] The University of Chicago
- [ ] The University of New Mexico
- [ ] The University of North Carolina at Chapel Hill
- [ ] The University of Texas at Austin
- [ ] The University of Texas at El Paso
- [ ] Tufts University
- [ ] Tuskegee University
- [ ] University of Arkansas
- [ ] University of California, Berkeley
- [ ] University of California, Davis
- [ ] University of California, Los Angeles
- [ ] University of California, Merced
- [ ] University of California, Riverside
- [ ] University of Colorado Boulder
- [ ] University of Colorado Colorado Springs

- [ ] University of Delaware
- [ ] University of Florida
- [ ] University of Georgia
- [ ] University of Houston
- [ ] University of Illinois at Urbana-Champaign
- [ ] University of Massachusetts Amherst
- [ ] University of Michigan
- [ ] University of Minnesota
- [ ] University of Notre Dame
- [ ] University of Oregon
- [ ] University of Pennsylvania
- [ ] University of Puerto Rico
- [ ] University of Tennessee-Knoxville
- [ ] University of Texas at Dallas
- [ ] University of Utah
- [ ] University of Virginia
- [ ] University of Washington

- [ ] University of Wisconsin-Madison
- [ ] Utah State University
- [ ] Virginia Tech
- [ ] Wyss Institute
- [ ] Yale University
- [ ] Not listed above, please specify:

_____

Q11 Please state the institution(s) primarily associated with your ${e://Field/ERC} role.

_____

End of Block: ERC Affiliation_2

Start of Block: Leadership Competencies

Q12 Section 2: Leadership Competencies

Q13 Please rate <u>how competent</u> you feel in doing the following activities in your professional space.
 * Being competent means having the necessary ability, knowledge, or skill to do something successfully.

	Not at all competent	Slightly competent	Moderately competent	Very competent	Extremely competent
Learning new skills throughout your career.	○	○	○	○	○
Taking on responsibilities that are not assigned to you.	○	○	○	○	○
Seeking out leadership opportunities.	○	○	○	○	○
Taking responsibility for the actions of people who report to you.	○	○	○	○	○
Acknowledging when you are wrong.	○	○	○	○	○
Providing creative ideas to solve problems.	○	○	○	○	○
Creating a shared vision for the group of people you work with.	○	○	○	○	○
Forming a group to accomplish a common goal.	○	○	○	○	○

Solving conflicts that arise within a group.	○	○	○	○	○
Balancing the financial, social, and environmental impact of your decisions.	○	○	○	○	○
Displaying empathy toward other people.	○	○	○	○	○
Treating other people with respect.	○	○	○	○	○
Listening to others' opinions even if they differ from your own.	○	○	○	○	○
Looking for opportunities to share your knowledge with others.	○	○	○	○	○
Explaining technical matters to people who are not familiar with your discipline.	○	○	○	○	○

Motivating others to accomplish predefined goals.	○	○	○	○	○
Encouraging others to take ownership of their work.	○	○	○	○	○
Creating a work environment in which people feel involved.	○	○	○	○	○
Helping people work through issues when they are stuck.	○	○	○	○	○
Facilitating developmental opportunities for others.	○	○	○	○	○
Praising others' achievements.	○	○	○	○	○
Adjusting how you interact with others based on their reactions.	○	○	○	○	○
Setting clear goals for a group project.	○	○	○	○	○
Planning tasks and resources for a group project.	○	○	○	○	○

Delegating tasks and authority for a group project.	○	○	○	○	○
Demonstrating technical expertise in work-related activities.	○	○	○	○	○
Staying current with new technologies in work-related fields.	○	○	○	○	○

Page Break

Q14 Please rate to what extent you think <u>your involvement with ${e://Field/ERC}</u> has <u>improved your competence</u> in doing the following activities.

	Not at all	Very little	Somewhat	Quite a bit	A great deal
Learning new skills throughout your career.	○	○	○	○	○
Taking on responsibilities that are not assigned to you.	○	○	○	○	○
Seeking out leadership opportunities.	○	○	○	○	○
Taking responsibility for the actions of people who report to you.	○	○	○	○	○
Acknowledging when you are wrong.	○	○	○	○	○
Providing creative ideas to solve problems.	○	○	○	○	○
Creating a shared vision for the group of people you work with.	○	○	○	○	○
Forming a group to accomplish a common goal.	○	○	○	○	○

Solving conflicts that arise within a group.	○	○	○	○	○
Balancing the financial, social, and environmental impact of your decisions.	○	○	○	○	○
Displaying empathy toward other people.	○	○	○	○	○
Treating other people with respect.	○	○	○	○	○
Listening to others' opinions even if they differ from your own.	○	○	○	○	○
Looking for opportunities to share your knowledge with others.	○	○	○	○	○
Explaining technical matters to people who are not familiar with your discipline.	○	○	○	○	○

Motivating others to accomplish predefined goals.	○	○	○	○	○
Encouraging others to take ownership of their work.	○	○	○	○	○
Creating a work environment in which people feel involved.	○	○	○	○	○
Helping people work through issues when they are stuck.	○	○	○	○	○
Facilitating developmental opportunities for others.	○	○	○	○	○
Praising others' achievements.	○	○	○	○	○
Adjusting how you interact with others based on their reactions.	○	○	○	○	○
Setting clear goals for a group project.	○	○	○	○	○
Planning tasks and resources for a group project.	○	○	○	○	○

Delegating tasks and authority for a group project.	○	○	○	○	○
Demonstrating technical expertise in work-related activities.	○	○	○	○	○
Staying current with new technologies in work-related fields.	○	○	○	○	○

Page Break

End of Block: Leadership Competencies

Start of Block: Leadership Understanding

Q15 Section 3: Leadership Understandings

Q16 Please rate your <u>level of agreement</u> with the following statements.

	Disagree	More disagree than agree	Neither agree nor disagree	More agree than disagree	Agree
Leadership is a role that only people who hold certain positions can occupy.	○	○	○	○	○
Only people who hold leadership positions are leaders.	○	○	○	○	○
Leader's job is to get the work done.	○	○	○	○	○
People not in leadership positions look to leaders for directions.	○	○	○	○	○
Leadership is a social process.	○	○	○	○	○
All group members participate in leadership regardless of their positions.	○	○	○	○	○

Anyone can be a leader regardless of whether they hold a leadership position.	○	○	○	○	○
Leaders' job is to serve other people.	○	○	○	○	○
Leaders' job is to develop others to also become leaders.	○	○	○	○	○
Leaders' job is to sustain a team or organization.	○	○	○	○	○
Leadership is being open to learning from others	○	○	○	○	○
Leadership involves lifelong self-development.	○	○	○	○	○
Leadership is working with others to accomplish changes from any place in the organization.	○	○	○	○	○

Leadership is being trustworthy to others in a group.	○	○	○	○	○
Leadership is a group attribute.	○	○	○	○	○
Leadership emerges through social interactions among all group members.	○	○	○	○	○
All group members influence each other through the course of leadership, whether intentionally or not.	○	○	○	○	○
Leadership is a skill or a combination of skills that an individual has.	○	○	○	○	○

Page Break

Q17 Please rate how <u>your involvement with ${e://Field/ERC}</u> has <u>influenced your opinions </u>on the following statements.

	Not at all	Very little	Somewhat	Quite a bit	A great deal
Leadership is a role that only people who hold certain positions can occupy.	○	○	○	○	○
Only people who hold leadership positions are leaders.	○	○	○	○	○
Leader's job is to get the work done.	○	○	○	○	○
People not in leadership positions look to leaders for directions.	○	○	○	○	○
Leadership is a social process.	○	○	○	○	○
All group members participate in leadership regardless of their positions.	○	○	○	○	○

Anyone can be a leader regardless of whether they hold a leadership position.	○	○	○	○	○
Leader's job is to serve other people.	○	○	○	○	○
Leader's job is to develop others to become leaders.	○	○	○	○	○
Leader's job is to sustain a team or organization.	○	○	○	○	○
Leadership is being open to learning from others	○	○	○	○	○
Leadership involves lifelong self-development.	○	○	○	○	○
Leadership is working with others to accomplish changes from any place in the organization.	○	○	○	○	○

Leadership is being trustworthy to others in a group.	○	○	○	○	○
Leadership is a group attribute.	○	○	○	○	○
Leadership emerges through social interactions among all group members.	○	○	○	○	○
All group members influence each other through the course of leadership, whether intentionally or not.	○	○	○	○	○
Leadership is a skill or a combination of skills that an individual has.	○	○	○	○	○

End of Block: Leadership Understanding

Q30 Section 5: Leadership Experiences

Q21 Please list any leadership experiences (both within or outside ${e://Field/ERC}) you have had during your involvement with ${e://Field/ERC} (e.g., Student Leadership Council, Mentoring, Tutoring, Coaching, Teaching, Managing, etc.).
 * Please indicate N/A if you do not have any leadership experiences.

_____

_____

_____

_____

_____

End of Block: Other Leadership Experience

Start of Block: Demographic information

Q22 Section 6: Demographic Information

Q23 How would you describe your gender identity?

_____

Q24 How do you describe your racial/ethnic identity? Please check all that apply.

- ☐ American Indian, Native American, or Alaska Native
- ☐ Asian or Asian American
- ☐ Black or African American
- ☐ Hispanic, Latino, or Spanish Origin
- ☐ Middle Eastern, North African, or Arab American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White or European American
- ☐ A race or ethnicity not listed above, please specify: _____
- ☐ Prefer not to answer

Q25 (optional) Please use the following space if you would like to provide any additional details that would further elaborate on your selections for racial/ ethnic identity.

_____

_____

_____

_____

_____

Page Break

Q26 Do either of your parents/ guardians have a bachelor's degree or higher?

- Yes
- No
- Prefer not to answer

Q27 Do you identify as a person with a disability, regardless of whether you have been formally diagnosed or typically request accommodations?

- Yes
- No
- Prefer not to answer

Q28 Are you now serving, or have you previously served in the military?

- Yes
- No
- Prefer not to answer

Q29 Are you a citizen or permanent resident of the United States?

- ○ Yes
- ○ No
- ○ Prefer not to answer

End of Block: Demographic information