ENGINEERING LEADER IDENTITY DEVELOPMENT

THROUGH REFLEXIVE INSTRUCTION

by

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DEDICATION

This work is in memory of my most unrelenting fan, Peter Tallman.

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ABSTRACT

Recent developments in engineering education have prioritized focus on developing leadership as a professional skill. Despite widespread efforts, indications are that the effectiveness of skill-based training is mixed, at best. One approach that has demonstrated promise is using identity as a lens for understanding leadership development. Its impact on engineering leadership is relatively unexplored.

This research strives to contribute to the field by measuring leader identity development due to instruction that leverages the lens of identity. In addition, the research explored the influence of engineering leadership construct (i.e., how students think about engineering leadership) and student class year on leader identity. A retrospective post-test measure was used to assess student leadership beliefs. Qualitative data (student essays, for example) supported interpretation of the quantitative data.

Results indicate that short-term reflexive instruction (focusing on values, language, reflection, and group work) significantly increases leader identity and changes leadership construct. Moreover, the perceived relationship between engineering and leadership is a significant predictor of leader identity. These findings provide a promising first look at the operationalization of an identity-based approach to engineering leadership development, as well as the relationship between leader identity and one's understanding of engineering leadership.

CHAPTER ONE

INTRODUCTION

When I first told my stepmother that I was researching engineering leadership, she asked, "Is that a thing?" I've had similar experiences with many outside of the engineering field (and some within), as they envision the "nerdy engineer" as the complete opposite of the charismatic leaders that grace the covers of business magazines. This difference may even be why many engineers are hesitant to call themselves leaders (Rottmann, Sacks, & Reeve, 2015). Yet, if we envision leadership in broader terms—for example, individuals guiding their team or project towards successful completion--engineering leadership seems a little less of an oxymoron (Bonasso, 2001).

1.1. Study Overview

This study will leverage identity frameworks to explore characteristics of engineering leadership development. Using the existing engineering leadership identity literature, features of identity-based instructional approaches will be established. These features will be used to design an identity-based instructional approach: here defined as *reflexive instruction*. The impact of a short-term reflexive instruction intervention on students in six lower- and upper-division engineering courses will be quantitatively measured. Quantitative analyses of changes in leader identity and engineering leadership construct (or what a student believes about engineering leadership) will be presented: subsequent discussion will be further supported by qualitative data. Implications for the field and limitations of the study will be discussed.

1.2 Problem Background

1.2.1 Leadership Development and Identity

Increased industry demands for leadership skills amongst engineering graduates has led to an explosion in engineering leadership programs in universities over the past 20 years (R. Graham, Crawley, & Mendelsohn, 2009). Many of these programs focus on specific leadership skills and behaviors. While these characteristic-based programs address important short-term and surface-level characteristics (Judge, Piccolo, & Kosalka, 2009), they seldom address more complex skillsets that require long term development (Lord & Hall, 2005). These programs have encountered many of the same difficulties that business schools have encountered trying to develop leadership capabilities of MBAs (D. B. Collins & Holton, 2004): the empirical evidence does not demonstrate that these programs substantively influence leadership development (Ahn, Cox, London, Cekic, & Zhu, 2014; Knight & Novoselich, 2017).

In the face of this difficulty, leadership scholars have invested more research in leadership development (e.g., Farr, Walesh, & Forsythe, 1997; Van Knippenberg, Van Knippenberg, De Cremer, & Hogg, 2005). Identity has emerged as one promising approach—how one sees oneself, and is seen by others, in society (Racine, 2015; Schell & Hughes, 2017a). The complexity, individuality, and staged natures of identity seem to provide a useful lens for leadership development (Lord & Hall, 2005). While this approach has seen use in leadership studies, it is only just emerging in engineering leadership: see Graham (2009) and Klassen et al. (2016) for reviews of existing engineering leadership program frameworks.

1.2.2. Engineering Leadership Development

Prior research has demonstrated that an identity approach holds promise in understanding and supporting engineering leadership development (e.g., Rosch & Imoukhuede, 2016; Schell, Hughes, & Tallman, 2020). Hence, the engineering leadership literature has increasingly explored the connection between identity and leadership development. Recent studies have begun to use an identity lens to interpret leadership development of engineering students (e.g., Edwards Jr & Pillapakkam, 2018; Schell & Hughes, 2017a). Others have used an identity lens to propose theories of engineering leadership development (e.g., Edwards Jr & Pillapakkam, 2018; Rottmann et al., 2015). And a few have quantitatively measured the impact of long-term leadership instruction on the leadership identity of engineering students (e.g., Montoya, Pacheco Rimada, Delgado, Webb, & Vaughan, 2015; Rosch & Imoukhuede, 2016).

The literature in the engineering leadership field has highlighted a potential source of engineering student reluctance to adopt a leader identity: a tension may exist between engineering and leadership. In other words, using an identity lens, some students may be reluctant to embrace a leader identity because it conflicts with their engineering identity. Some have suggested that the charismatic model of a leader / hero is inconsistent with that of the rational and scientifically grounded engineer (e.g., Mumford et al., 2002; Schell & Hughes, 2017b). And, suggestions have been made about how to address this tension, so that engineering students might be less resistant to leadership roles (Rottmann et al., 2018). Yet, empirical evidence that demonstrates the existence of this tension and its impact on student leader identity is mixed (compare Ahn et al., 2014;

Dugan, Fath, Howes, Lavelle, & Polanin, 2013; Stephens & Rosch, 2015). Moreover, the field lacks empirical evidence that demonstrates the effectiveness of instructional approaches or experiences that might address this tension (if it exists).

Finally, a core characteristic of development, by definition, is its dynamic nature. Hence, factors driving student engineering leadership identity development may vary by student class year. While identity theories provide rich insight into how college students develop in general ways, far less is known about engineering leadership identity growth amongst engineering majors. As a result, educators lack a research-based foundation for developing programmatic and course-based approaches to engineering leadership growth that are developmentally relevant.

1.2.3. Identity-based Instruction

As a result of the increasing engineering leadership literature focus on identity, understanding of its importance to student leadership development is growing. However, the current understanding of how this approach might be operationalized is still in its infancy. Common practices known to support identity growth (e.g., reflection, technical and social skills, peer learning, alignment of values, etc.) are cited widely in the literature, often as implications for practice (e.g., Klassen, Kovalchuk, Reeve, & Sacks, 2017; Neeley, 2015; Nino, 2016). Yet, empirical evidence measuring the impact of these practices (in an engineering leadership context) on student identity is limited, at best. As a result, the field has yet to coalesce around specific practices that cultivate engineering leadership identity.

1.3. Problem Statement

While the current engineering leadership identity literature is beginning to explore the impact of identity on engineering leadership development, three gaps in the literature emerge upon examination of the field. First, an instructional approach that is grounded in the literature and leverages identity to cultivate engineering leadership development has not yet been widely established. Moreover, the impact of such an approach on leader identity has not been empirically demonstrated. Second, an understanding of if and why engineering students are resistant to leadership has mixed empirical support. In particular, the potential tension between engineering and leadership has not yet been empirically supported. In other words, the field has yet to empirically measure which aspects of student engineering leadership beliefs (if any) may conflict with their engineering identity. Third, ways in which lower- and upper-division students may developmentally differ in terms of engineering leadership has not yet been quantitatively established.

1.4. Study Purpose

The overall purpose of the study is to understand the impact of identity-based instruction on engineering leadership identity. An important aspect of this purpose is the relationship between student engineering leadership construct and leader identity. For example, do students with more power-based views of engineering leadership feel more like leaders, or less? What if they see engineering leadership as something that can be shared by multiple team members?

More specifically, the purpose of this quantitative research study is to measure the impact of a short-term identity-based intervention (i.e., *reflexive instruction*) on the leader identity of engineering students. This study will furthermore seek to empirically explore the connection between engineering leadership beliefs (i.e., *engineering leadership construct*) and leader identity. Finally, this study will quantiatively measure the relationship between student development and engineering leadership identity growth.

Core variables of interest are leader identity and engineering leadership construct. In addition, demographic (e.g., gender) and related control variables (e.g., previous leader experience) will be recorded; other outcomes relevant to engineering leadership identity will also be explored (e.g., leadership interest). Relationships between engineering leadership construct and leader identity will be measured. In addition, relationships between class year and variables of interest will be assessed. The study includes engineering students from six lower- and upper-division engineering courses at two Rocky Mountain public universities. All students in the chosen courses were invited to participate in the research. Course selection was based on criteria relevant to the research purpose, with convenience sampling guiding the selection of courses that met the criteria. Qualitative data, collected during the intervention, will be used to support discussion of quantitative findings.

1.5. Research Questions

The research purpose has led to the development of five research questions. Answering these questions will enable the study to address existing gaps in the

engineering leadership identity literature. The research questions guiding this study are the following:

RQ1: Does reflexive instruction about engineering leadership influence leader identity?

RQ2: Does reflexive instruction about engineering leadership influence engineering leadership construct?

RQ3: Does engineering leadership construct influence leader identity?

RQ4: Does reflexive instruction about engineering leadership influence lower-division students' leader identity differently than it influences upper-division students' identity?

RQ5: Does reflexive instruction about engineering leadership influence lower-division students' engineering leadership construct differently than it influences upper-division students' construct?

The first two research questions address the direct impact of reflexive instruction on the participants. Research question three explores the connection between engineering students' beliefs about engineering leadership and their own leader identity. The final two research questions (RQ4 and RQ5) explore differences between participants as a function of class year.

1.6. Definition of Terms

Identity (or self-identity): "The authoring of a self within a context" (A. Johnson, Brown, Carlone, & Cuevas, 2011, p. 344). More simply, how one sees oneself, and is seen by others, in society.

Leader identity: How one sees oneself as a leader. In self-schematic literature, this is often expressed in terms of descriptiveness, interest, and confidence (Hiller, 2005).

Leadership: "Leadership has been characterized as the capacity to exert individual influence in order to promote the continued success of the members of the work unit or team and, as a result, of the firm as a whole" (Northouse, 2015, as cited in Klimoski and Amos, 2012).

Leadership construct: The orienting framework that defines the content and boundaries of leadership in a particular environment or condition.

Meaning-making: The process of an individual perceiving and organizing one's live experiences based on assumptions (Abes, Jones, & McEwen, 2007, p. 4).

Pedagogy: The Oxford Dictionary defines it as "the method and practice of teaching." Here, *pedagogy* is being used in a more expansive way to include experiences, interactions, ways of learning or teaching, and even skills that might be associated with broad instructional strategies.

Reflexive leadership instruction: Instructional approaches about leadership that foreground reflection, group work, language, and values, while integrating an identity lens.

Self-authorship: The state of "evaluating one's own views in light of existing evidence and constructing a reasonable perspective as a result…. [As well as being able to] …be influenced rather than to be consumed by others' perspectives…" (Baxter Magolda, 1998, p. 144).

Self-efficacy: A measure of one's judgment that they can successfully perform a task (Paglis & Green, 2002).

Self-schema: "cognitive generalizations about the self that organize and guide the processing of self-related information" (Markus, 1977).

1.7. Conceptual Frameworks

Because identity is such a complex, richly researched topic, studying its use purely within the context of engineering leadership would omit much of the insight that other fields have established on its characteristics. Hence, this research will adopt frameworks from increasingly focused identity aspects, each rooted in a particular literature stream:

1. Personal identity
2. Professional identity
3. Engineering identity
4. Leader identity.

Each of these identity frameworks provide insight into a unique aspect of one's identity, and all four are required for informed exploration of engineering leadership identity. The literature review will start with personal identity to get an understanding of the dominant developmental process that college students experience: self-authorship, or the ability to construct one's own views (Baxter Magolda, 1998). From there, professional identity frames the importance of one's work to the self. This study will adopt the Community of Practice model, which—based on historical apprenticeship models—frames a profession as a community of experts surrounded by potential

participants (Lave & Wenger, 1991). Engineering identity informs the ways in which engineering students (and professionals) see themselves as unique and a member of this selective profession. The Performance / Competence / Interest / Recognition (PCIR) model will guide utilization of an engineering identity lens (Carlone & Johnson, 2007; Hazari, Sonnert, Sadler, & Shanahan, 2010). Finally, leader identity provides insight into how someone sees themselves as a leader. The Leadership Identity Development (LID) model describes a six-staged process of moving from a positional to a relational view of leadership (Komives, Owen, Longerbeam, Mainella, & Osteen, 2005).

1.8. Research Design

1.8.1. Literature Review Purpose

Equipped with conceptual frameworks rooted in four well-developed identity fields, an informed reading of the current state of engineering leader identity will be accomplished using a systematic literature review approach. Its purpose is to identify the state of the field and to identify which instructional features develop engineering leadership identity. Review of the literature found four core features of identity-based instruction: reflection, group-work, vocabulary, and values. These four features were operationalized using teaching good-practices: the resultant approach was defined as *reflexive instruction*. Defining reflexive instruction was essential to the research design, as it provided an instructional approach that could effect engineering leadership identity development in a controlled classroom environment.

1.8.2. Study Procedures

The impact of reflexive instruction about engineering leadership was quantitatively measured through a pre-survey and a retrospective post-survey. Core variables are measured by multiple factors that have been previously validated. Remaining survey items were either directly pulled from or based on previously published measures. 166 engineering students from two institutions and six engineering courses participated in the short-term (1-2 classes, based on class year) intervention. Identifying information for each student was tracked throughout the research process (i.e., pre-survey and retrospective post-survey responses can be matched): all identifying data has been subsequently removed to maintain student confidentiality.

The intervention included reflective assignments, group and classroom discussions, and related group activities. In addition, a pilot study, conducted in Spring 2020, informed the present study design. Finally, the reflective assignments and classroom discussion provided qualitative data to support interpretation of the quantitative analysis. The research was conducted Spring 2021.

1.9. Study Significance

This study was conducted under the view that leadership is an essential component of the engineering profession. While technical competence has long been the litmus test by which engineers are defined (e.g., through classroom exams or the professional engineering exam), these competencies are acknowledged as a necessary, but insufficient, skillset for effective engineering practice. Because today's engineering

challenges involve cross-disciplinary teams, professional skills are essential for engineering success. Hence, adequate training of future engineers includes both requisite technical competence as well as the professional skills necessary to effectively contribute to team success. Without these professional skills, engineers' technical expertise may fail to inform project decisions, leading to suboptimal solutions (at best) or catastrophic failure (at worst).

This study's findings may help those in the engineering profession to effectively train, guide, and mentor new engineering graduates. By supporting their continued professional development, these engineering graduates are better equipped to take responsibility both for their own professional growth and for their technical contributions to project success. For example, these findings may highlight ways in which engineering graduates' perspectives and beliefs may diverge from those of the profession. Focusing on these beliefs, and the values they reflect, may help align engineers' values with those of the profession. This alignment has the potential to support long-term commitment to the engineering profession. This long-term commitment enables technical mastery, which benefits an employee's company, the company's field, and everyone served by that field.

This study is important to researchers in the engineering leadership field. For example, they may benefit from the establishment of an instructional approach that has been empirically shown to increase leader identity amongst engineering undergraduates. This instructional approach provides an important first step in understanding the processes present in engineering leadership identity development. With an empirically

grounded foundation, researchers are better equipped to quantitatively explore causal mechanisms of engineering leadership development in more detail and under different conditions. For example, researchers could explore conditions that support (or hinder) development, and causal (or mediating) relationships between engineering leadership related variables.

This study is also important to engineering educators. While institutions vary in their support of engineering leadership development initiatives, the demands placed on professors are extensive almost everywhere. In addition to furthering knowledge in their field of expertise, they are expected to support institutional and departmental initiatives, advise undergraduate and graduate students, navigate student feedback, and build a case for promotion. Throw in the responsibility of teaching well, and it is no surprise that instructors teach the way they were taught. The development of a short-term instructional module that can be easily integrated into existing course structures provides an accessible way to effectively support engineering leadership growth with minimum effort. Moreover, scaling this type of instructional module for online or hybrid engagement models could greatly multiply its impact.

In addition, these findings are helpful for those educators who have the disposition and opportunity to continually innovate in their own teaching. These educators may leverage empirically based research findings to design evidence-based instructional approaches or experiences. Related, findings from this study may be important to educators who administer engineering leadership programs. Innovations in research provide evidence that informs programmatic decisions. For example,

administrators may shift lower-division activities to highlight the relational aspects of leadership, if the empirical research findings support it. By enabling evidence-based approaches to programmatic design, both program effectiveness and reach (in terms of inclusion) may be extended. As a result, college engineering educators and administrators may provide an education that more fully and effectively prepares students for the engineering profession.

Finally, this study may be especially important to engineering students. The current education system widely focuses on technical competency. This prepares students for the basic problem-solving and analytical approaches required for technical components of their job. While changes are in-progress through such channels as ABET standards and certification, these changes are slow and gradual. As a result, students are generally left to their own devices when it comes to developing professional skills. This leads to haphazard training in professional skills, at best. At worst, it leads to an education that excludes those interested in expansive ways of professional engagement: some scholars suggest this propagates an environment that excludes women (Faulkner, 2000, 2007; Hatmaker, 2013). In turn, the engineering profession itself is damaged by the exclusion of the very engineering students that might most benefit the profession.

In sum, the findings of this study have significance to multiple stakeholders related to the engineering profession, including everyone impacted by engineering solutions (such as phones, bridges, and cars). By taking an important first step towards evidence-based professional skill development, findings from this study contribute to

better-trained engineers who are able to more effectively take responsibility for addressing the challenges that society sends their way.

1.10. Summary

This research is intended to contribute to a growing body of knowledge on how to effectively cultivate engineering leadership identity amongst undergraduate students. Specifically, this study will identify and measure the impact of short-term reflexive instruction, measure the impact of one's beliefs about engineering leadership on one's own leader identity, and identify ways (relevant to engineering leadership growth) in which lower-division students differ from their upper-division peers

This dissertation will continue with a Literature Review (Chapter 2). This chapter will inform the Research Agenda and Methods that form Chapter 3. Chapter 4, Analysis, will address research questions and hypothesis testing. Finally, Discussion (Chapter 5) will present the analysis results within the context of the study purpose. Limitations and implications (for both theory and practice) will also be included in the final chapter.

CHAPTER TWO

LITERATURE REVIEW

Given the potential benefits of an effective identity-based approach to engineering leadership development, this second chapter will explore the relevant literature. More specifically, this chapter will integrate research from several adjoining fields to inform a Systematic Literature Review. The findings from this literature review will provide frameworks for understanding engineering leader identity development, and they will provide insights into activities that cultivate it. The strategy is composed of three steps, per Figure 1. First, identity-based frameworks will be adopted from four adjoining fields of literature: personal identity, professional identity, engineering identity, and leader identity. From each framework, core identity concepts, developmental transitions, and

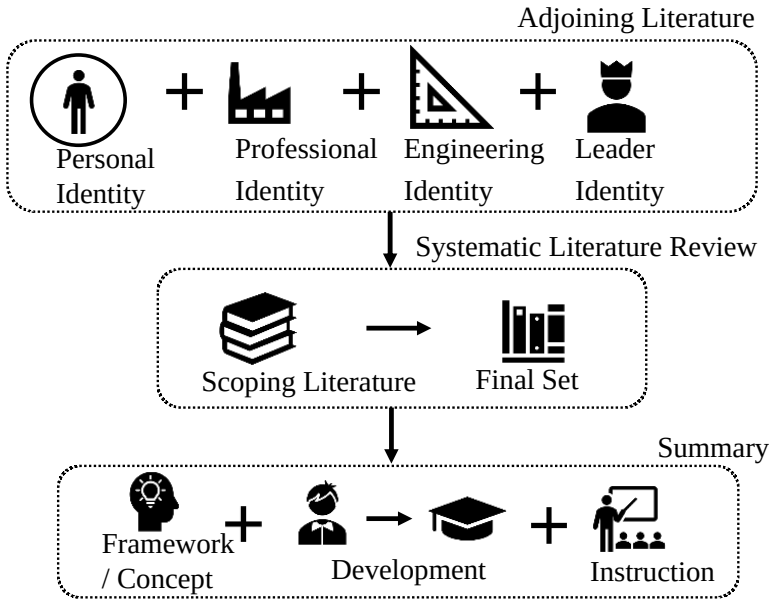

Figure 1. Literature review strategy.

experiences will be addressed, per Figure 2. Cumulatively, these provide a context for examining the engineering leadership identity literature.

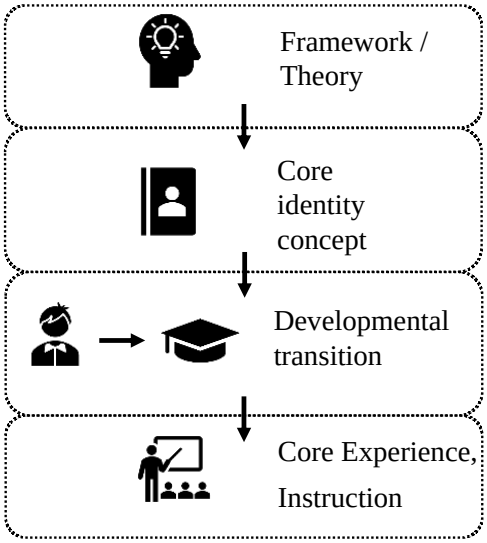

Figure 2. Identity framework facets.

Following the adjoining literature review, a systematic literature review of the engineering leadership identity field will be presented. The approach for this component of the literature review is informed by Keathley's (2014) Systematic Literature Review (SLR) process. This process was used to review the engineering leadership identity literature. Keathley's approach was developed within an engineering education milieu,

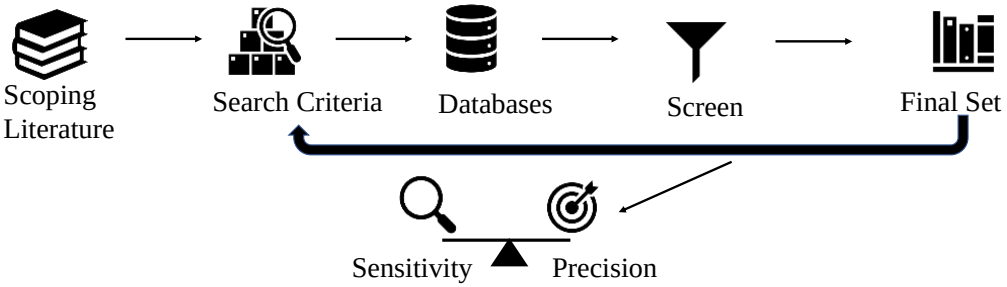

Figure 3. Systematic literature review process.

and is largely informed by Tranfield, Denyer, and Smart's (2003) work in management (Keathley et al., 2014). This SLR consists of five core elements to explore literature (Figure 3): scoping literature (where core literature is established), search inclusion criteria, search databases (similar to a traditional literature review), screening exclusion criteria, and final literature set. Once additional literature has been found, search and screening criteria are revisited to either expand or contract the database search. This choice depends on the researcher's priority for sensitivity (finding more possibly relevant literature) versus for precision (identifying truly relevant literature). This process is iterative, until a final literature set has been identified that includes the scoping literature and a robust collection of related literature. An important metric during this stage is the 'Capture Rate,' which is the percentage of the scoping set that is captured in any given search—higher is better, per Equation A:

$$\text{Capture Rate} = (\text{Scoping members found}) / (\text{available}) \qquad \text{[Equation A]}$$

Third, the state of the field of engineering leadership identity will be summarized, leading to informed research questions that address gaps in the literature. Specifically, the literature was evaluated in terms of the literature review guiding question: "What are features of instructional approaches or experiences that develop engineering leader identity?" Instructional features referenced by the literature were analyzed for emergent categories that answer the literature review guiding question. These emergent categories provide an orienting typology of experiential and instructional characteristics that cultivate engineering leader identity. Hence, the literature review purpose directly addresses explicit gaps in the field: for example, "…there is a clearly articulated demand

for better research [in] the development of a clear typology of specific [engineering leadership] program elements…" (Klassen et al., 2016, p. 16).

2.1. Adjoining Fields

2.1.1. Field Strategy

Before systematically examining the relatively young field of engineering leadership identity, four adjoining fields provide useful insight, as well as sound theoretical frameworks: personal identity, professional identity, engineering identity, and leader identity (Figure 4). The purpose of exploring these fields is because they offer robust insight and mature scholarship on important concepts, developmental processes, and experiences that inform one's reading of the engineering leadership identity literature. These fields contextualize engineering leader identity, providing an antidote to the liabilities of the fragmentation of academic fields results (e.g., unproductive research due to ignoring relevant stakeholders) —Tranfield et al. (2003, pp. 211-212) provide additional rationale for this stance. Using theories from multiple adjoining fields enables

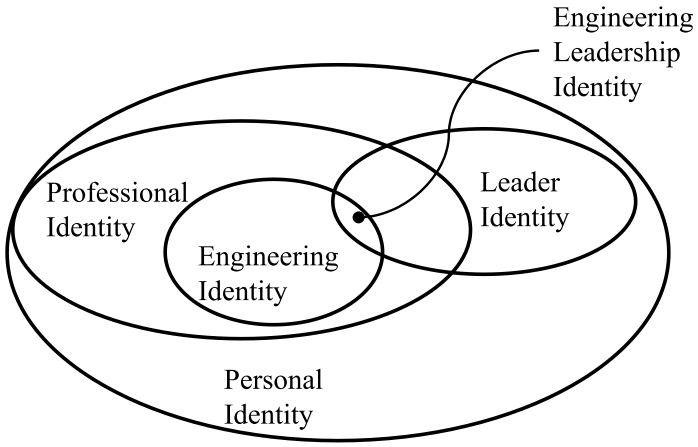

Figure 4. Identity fields.

appropriate application of theory and a "…holistic understanding of students" (Komives et al., 2009, p. 22). In fact, Dugan (2011) claimed that, in order to move past a behavior-based view of leadership, "[r]esearchers need to better triangulate processes associated with social identity, cognition, psychosocial, and moral development with leadership development to offer greater insights into learning thresholds and leverage points" (p. 81). Exploration of these four fields will follow the format for identity framework facets outlined in Figure 2.

2.1.2. Identity Overview

While Science, Technology, Engineering, and Math (STEM) education is a field of study with a long history of skill development, recent research has integrated theories of human development, borrowed from the social sciences (e.g., Godwin, Potvin, & Hazari, 2013; Prince, 2004; Wieman, 2015). One such framework is identity, which addresses how individuals author themselves within a particular context (A. Johnson et al., 2011). A popular influential model rooted in psychosocial theory (Meyers, 2009) outlines seven vectors in which identity operates, per Figure 5 (Chickering & Reisser, 1993). This model demonstrates the breadth, interdependence, and complexity of identity in human experience.

Of particular interest to educators, identity provides insight into motivation and related behaviors during development, making it useful for understanding retention in engineering programs. Identity also provides a framework for understanding the complexities and individual nature of student development (Gee, 2000). Finally, identity provides a framework for dealing with dynamic staged processes, such as are

encountered during the transformative experiences that typically characterize the undergraduate journey (Terenzini & Reason, 2005). Some suggest that this personal development is every bit as important as technical mastery in becoming an engineer, leading to one scholar's conclusion that engineering education is—by definition--engineering identity formation (Tonso, 2014, p. 267).

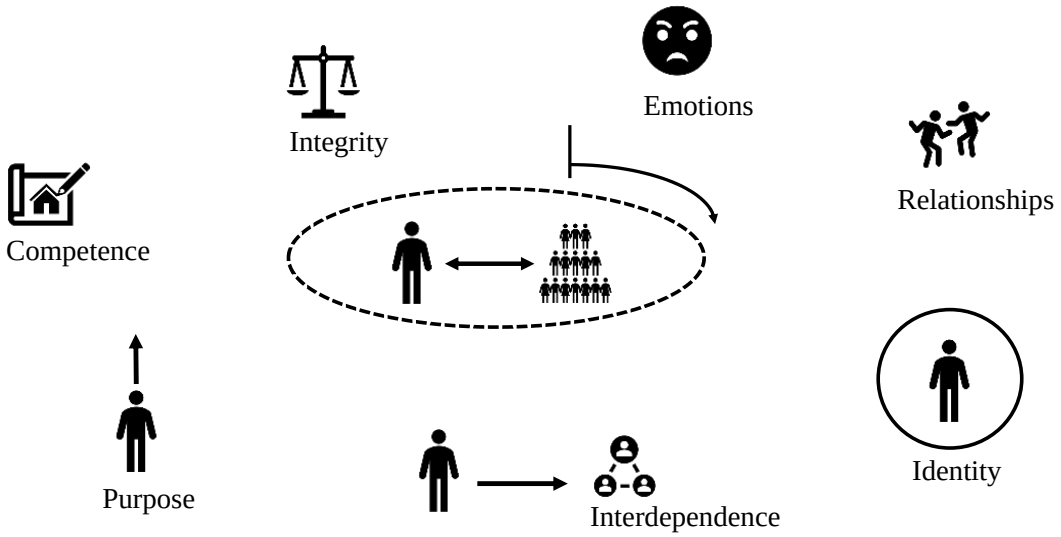

Figure 5. Personal identity vectors.

While not the first to propose the idea of identity, Erik Erikson's (1950) 8-staged theory has provided the foundation for continued identity work (Meyers, 2009, p. 12). By combining the fields of psychology and sociology, Erikson established a psychosocial perspective on an individual's view of themselves and their relationship with surrounding society (Marcia, 1966). While several lines of research (and levels of analysis) followed from Erikson's theory (e.g., Chickering & Reisser, 1993; Marcia, 2002 ; Pascarella & Terenzini, 2005), this research will focus on a broad psychosocial view of development, following the seminal work of Chickering and Reisser (1993). Their work suggests that identity develops in increasingly complex ways of thinking, knowing, and doing.

2.1.3. Personal Identity Lens

One seminal identity theory that is particularly useful describing college age development is Kegan's (1982) 6 stages of self-consciousness. This theory describes the increased locus of control in interpersonal relationships but has been extended to cognitive growth, as well. Kegan suggests that individuals move from merely controlling impulses to acting as an interdependent influential being as they develop. One approach, based on Piaget's (1955) work, that Kegan found useful in helping individuals through this transition is subject-object inquiry, where the distinction between one's previous perceptions and reality were probed. Important to this approach is exploring the limits and boundaries of one's self-knowledge, which might be accomplished by asking about changes in beliefs (Kegan, 1982).

Baxter Magolda (1998) extended Kegan's (1982) work by exploring the impact of meaning-making on development. Meaning-making structures "…are sets of assumptions that determine how an individual perceives and organizes one's life experiences" (Abes et al., 2007, p. 4). According to this model college students are characteristically at stages (or orders) 3 –4 of Kegan's 6 Orders of the Mind (Marcia B. Baxter Magolda, 2000). Order 3 is characterized by externally imposed meanings, called "formulaic" meaning making (being dependent on others' input). As students develop self-authorship, they progress to "foundational" meaning making (being dependent on one's own interpretations and beliefs), corresponding with Kegan's Order 4. In summary: the "[Order 3 self] co-constructs their sense of meaning with other persons and sources in their environment… [T]he [Order 4] self can internalize multiple points of view, reflect on them, and construct them into one's own theory about oneself and one's

experience" (Marcia B. Baxter Magolda, 2000, p. 8). In between these two stages, individuals struggle with the tension between internal values and external pressures in their effort to establish their own firm convictions, hence the term "transitional" meaning making (Marcia B. Baxter Magolda, 2000).

Self-authorship describes the ability of an individual to create their own knowledge and to reflectively engage with others (in interpersonal, intrapersonal, and cognitive domains). It is critical to students' development as it reflects their psychological differentiation from co-constructors of childhood; through it, they begin to distinguish ideas grounded on the internal self from those grounded on others' influence. More it is essential for pursuing self-directed skills, such as complex, personal and non-linear skillsets, such as leadership (Marcia B. Baxter Magolda, 2000). Specifically, Baxter Magolda found that self-authorship consisted of four pillars in her qualitative research of 39 young adults: "learning how to make knowledge claims [i.e., trusting yourself], gaining confidence in doing so, learning to balance external forces with one's own perspective and knowledge, and developing an internal identity that supports acting on one's knowledge and priorities [i.e., acting on one's environment effectively]" (Baxter Magolda, 1998, p. 153).

Later research by Barber, King and Baxter Magolda (2013) used this approach to more fully explore how self-authorship development occurred amongst college students. Their research of 30 college students found that experiences that demanded sophisticated meaning-making "…promoted substantial developmental shifts." (p. 866). More specifically, this research found that self-authorship grew when students were expected to

create their own views and take responsibility for them (p. 878); self-authorship also grew when critical approaches were scaffolded in class concurrent with guidance and support from both supportive faculty and peers (p. 879).

Baxter Magolda (2000, pp. 12-13) further describes why tertiary institutions often impede self-authorship development: "The problem is that instructors in college expect order 4 ownership and critical thinking, which is developmentally mismatched with student order 3" (p 3). As a result of their research, Barber et al. (2013) suggested more experiences for students where they could take ownership of their growth in partnership with peers, where they could work with culturally diverse others, and where they are able to "select groups that match their values yet challenge them to think differently…" (p. 890). Chickering and Reisser (1993) were also highly critical that the typical college environment does not cultivate Order 4 self-consciousness. Colleges focus on limited skills instead of shaping priorities; rote learning instead of meaningful learning; competitive grading at the expense of developing interpersonal relationships; and established knowledge instead of ways of thinking (Chickering & Reisser, 1993, pp. 274-275, 344-347).

To address these shortcomings of the college environment, several changes might cultivate a student's identity more productively. First, technical content might be explored within the context of developing creative solutions that serve the public interest (thereby giving value and meaning to technical skills). Second, collaborative engineering projects working towards an authentic, practical goal could highlight the value of interpersonal relationships on meaningful projects (thereby scaffolding collaborative peer

engagement towards a shared common goal). Third, instructors could provide opportunities for engineering students to critique business case studies, so they can see the value of engineering ways of thinking in tangential fields (thereby introducing students into more holistic problem-solving that is characteristic of the profession). By shifting the focus of the institutional environment in these ways, one can begin to envision a more meaningful, value-laden, connected education as learners cultivate a more developed personal identity (Chickering & Reisser, 1993).

2.1.4. Professional Identity Lens

One vector of one's overall identity that is especially important for this research is that of competence, which is central both to professional identity (Klemp, 1977) and college student identity development (Chickering & Reisser, 1993, pp. 45-46, 53-82). One characteristic of identity is that it is activated in certain contexts. Hence, one's professional identity may act as an important influence on overall identity, just due to the time spent at work or school. For obvious reasons, this lens is of particular interest to studying the profession of engineering. The evidence suggests (unsurprisingly) that as engineering students continue through the curriculum, their connection with the engineering profession strengthens (e.g., Dehing, Baartman, & Jochems, 2011; Patrick, Borrego, & Prybutok, 2018; R. Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008). Finally, because identity is intertwined with the social situation in which one finds oneself, professional identity may have unique characteristics based on the social norms and values of the professional community.

2.1.4.1. Competence Vector. Professional identity may be understood within the larger context of personal identity, as how people position themselves as competent individuals. Based on Klemp's (1977) research on professional success, Chickering and Reisser (1993) proposed that professional identity could be envisioned as a pitchfork: they defined this as the Competence vector of identity. The pitchfork has three tines: the intellectual, physical, and interpersonal skills needed to succeed in one's profession; and the handle is one's self-efficacy. Self-efficacy is a measure of one's judgment that they can successfully perform a task (Paglis & Green, 2002). The handle makes tines functional in an actual pitchfork, and so it is here—one's self-efficacy at work empowers one to make use of intellectual, physical, and interpersonal skills. Self-efficacy may play different roles amongst different populations: for example, Dugan (2011) suggests that promoting capability more than efficacy in leadership training may be especially problematic for underserved populations.

2.1.4.2. Community of Practice. The Community of Practice (CoP) (Lave & Wenger, 1991) model is a widely adopted framework in the professional identity literature that has been useful in understanding engineering identity (Hughes, Schell, & Tallman, 2019b; Li et al., 2009; Rottmann et al., 2018). Lave and Wenger (1991) proposed the Community of Practice model-- which consists of members of a professional community who surround a core of practicing experts—based on research of apprenticeship in the trades. Fundamental to this community is a group of members that have not yet fully engaged, called legitimate peripheral participants (LPP). These LPP—often newcomers who have demonstrated a commitment to joining the community but

have yet to actively participate-- experience a type of 'benign neglect' where the community tolerates their presence without encouraging their engagement. Through incremental practice and feedback in their fields of expertise, these newcomers may accrue community recognition. Wenger (1998) later explored the importance of these dynamics, suggesting that non-participation is essential to the formation of identity, as it emphasizes one's agency in how one chooses to participate. The process of fuller membership involves moving from a passive observer with ambivalent thoughts about their profession to an engaged professional demonstrating expert-like behaviors, dialogues, and commitments. An important characteristic of a CoP is that legitimacy is negotiated through community recognition of one's performance, with higher legitimacy leading to more central communal roles (Wenger, 1998, pp. 172-173). It should be noted that there have been a number of developments of Lave and Wenger's original model (Barnett, Jones, Bennett, Iverson, & Bonney, 2012; Li et al., 2009), but the core ideas are sufficient for the scope of this review.

Another component of this framework is situated learning, where learning occurs within a particular context, as learners struggle to make meaning of their experience and knowledge. As outlined by Dennen and Burner (2008), the CoP model includes three components that are especially relevant to situated learning: modeling, scaffolding, and coaching. Modeling involves learner observation of direct demonstration of expert practice. This aspect of learning is especially relevant in internships, where professionals demonstrate effective practice, and interns observe. Scaffolding involves learner practice with "gradual withdrawal of teacher from the process… so that students can learn to

accomplish cognitive challenges." (Dennen & Burner, 2008, p. 814). In the classroom, scaffolding may include student participation in classroom activities or challenging and clarifying student understanding. Finally, coaching involves learner reflection about thinking and practice, facilitated by instructor feedback. This approach bridges the developmental chasm between learner as novice and learner as active agent in their own identity development (Dennen & Burner, 2008).

Classroom examples of situated learning include one-on-one project discussion between learner and instructor (as co-participants of authentic, complex tasks), or written student reflection on performance with instructor feedback. Dennen and Burner (2008) suggest that this type of situated model empowers engineering students to not only learn about engineering, but to truly begin to practice like (and identify with) practicing engineers. Wenger conceptualized this learning as having four components:

1. community- learning as belonging,
2. practice-- learning as doing,
3. meaning-- learning as experience, and
4. identity-- learning as becoming. (Wenger, 1998)

Wenger's (1998; 2002) later work addressed the tension between a situated learning view of professional development and the type of training typically experienced in post-secondary professional preparation. He argued that there are three important ways traditional university-based professional training handicaps student professional growth. First, he argued that a teacher-centered model of education inhibits student growth by shifting the focus to external validation. Teachers establish the boundaries of

knowledge and criteria for minimum competence (grades) thereby promoting externally imposed knowledge boundaries, hence limiting the students' own agency, legitimacy, and internal motivation. Second, he argued that because of this teacher-centered model, learners are not afforded the opportunity to pursue individual interests, which are necessary for honing expertise and internal validation. Third, he argued that universities seldom contextualize knowledge within a practicing community: by being isolated, students' ability to engage with the engineering profession is limited, adversely affecting persistence in their major, perceived legitimacy, and preparedness to enter the profession (Wenger, 1998).

In his later exploration of communities of practice, Wenger (1998) proposed three core changes to the college curriculum that would cultivate more authentic, healthy identity development, based on the CoP idea of belonging. CoP members cultivate a sense of belonging with the group through three modalities: imagination (i.e., how can I see myself as a member?), engagement (i.e., how can I participate in this community?), and alignment (i.e., how do my values align with this community's?). Wenger's changes addressed each of these. First, the education environment should provide materials and experiences with which one may imagine all the possible paths one may take. Wenger suggested this could be achieved by students doing the following: orienting their location and trajectory within the broader world—identity as an expanding image of the world; reflecting on their own self—identity as self-consciousness; and exploring possible worlds and selves—identity as creation. Second, the education environment should provide a place of engagement. Practical steps outlined here include activities requiring

mutual engagement, challenges that depend on both existing knowledge and creative exploration for success, and a curriculum that provides enough continuity for participants to develop long-term commitment to an idea and their peers.

Third, the education environment should cultivate alignment between meaningful work and one's sphere of influence. Wenger (1998) here outlined four ways to explore alignment: engage with other communities for a common purpose (this provides a shared vision that is bigger than the local community); provide varied ways of being a member (this limits the impact of community exclusionary behaviors, as well as provides insight for heterogeneous ways of being); be self-conscious about the types of conversations that are part of community dialogue (this empowers the community to be reflective about their own norms); and engage with the institutional arrangement that defines the context of the community (this allows the community to engage with institutional identity in a meaningful way) (pp. 271-272).

In summary, Wenger proposes an education environment that supports student identity development and education. This is achieved by connecting with ways of practicing that are authentic, agentic, and meaningful. Characteristics of such practices are supporting student imagination (and exploration), promoting student engagement in an authentic and challenging way, and cultivating student alignment between their own values and their own learning (Wenger, 1998). Situated learning theory suggests that immersing students in these authentic, agentic, and meaningful experiences enables students to develop in a way that more closely aligns with the engineering profession (Lave & Wenger, 1991).

2.1.4.3. Provisional Self. Ibarra's "provisional selves" has been particularly useful in understanding the mechanisms of professional identity development (Ibarra, 1999). The transition of participants into new professional roles involved a three-stage process that included observing role models, experimenting with various perspectives (called provisional selves), and adjusting to feedback on performance. This type of process provides further insight into leadership (Ibarra, Snook, & Guillen Ramo, 2010), as well as imagination and alignment CoP models of belonging (Lave & Wenger, 1991). Further research demonstrated that Ibarra's "provisional self" stages were important to student connection to engineering (compared to a mentorship experiences, which provided clarity of understanding of the engineering profession). This indicates that while mentorship can be a powerful tool in professional identity, its socializing influence may be adversely external. Hence, the development of a personal alignment with a professional identity requires agency, such as an engineering student trying on various ways to act like an engineer in an authentic context (Dehing et al., 2011).

2.1.4.4. Expectation Value. Eccles's (1983) "expectation value" theory has been widely leveraged to understand both professional and leader identity development (e.g., Ibarra, 1999; Meyers, 2009). This theory addresses the causes of motivation, which has been shown to lead to persistence in complex tasks, such as degree completion and personal development (Matusovich, Streveler, & Miller, 2010). The causes of motivation are a combination of a value for the goal (value) and an expectation of success (expectation). The value for a goal is called "subjective task value" and is comprised of

four components, which Matusovich (2010) operationalized for the engineering profession:

- "…attainment— I am a problem-solver and engineers are problem solvers…
- cost— Being an engineer means not being able to pursue interests in art…
- interest— engineering is the career name for the hobbies I enjoy…
- utility— engineers are well-paid" (p. 294).

2.1.5. Engineering Identity Lens

Literature in professional identity development provides a global view of how novices join and participate in professional communities, yet many maintain that the ways engineers navigate this experience are unique, even compared to other autonomous professions (e.g. Godwin et al., 2013; Lichtenstein, McCormick, Sheppard, & Puma, 2010; Matusovich et al., 2010; Stephens & Rosch, 2015). Because of this, there exists a broad literature base that has explored engineering identity using various approaches, such as critical, developmental, and professional characteristics (Morelock, 2017; Patrick & Borrego, 2016).

Stevens (2008)—in a longitudinal ethnographic case study of college students--outlined three similar "dimensions" of engineering identity by suggesting that technical competence and recognition were vital—but added navigation of pathways to the list to reflect the types of formative experiences that successful engineers shared. Along these lines, Meyers (2012, p. 119) reformed the question into core skills and behaviors, finding that making competent design decisions, working with others, and accepting

responsibility were essential for engineering success. And Loui (2005, p. 385) outlined four essential components of ideal Professional Engineers:

1. Technical competence
2. Interpersonal skills
3. Work ethic
4. Moral standards.

While these and many other approaches to understanding engineering identity have been proposed, the Performance/Competence, Interest, Recognition (PCIR) model has been widely cited as a lens for engineering identity (e.g., Godwin, Potvin, Hazari, & Lock, 2016; Hughes, Schell, & Tallman, 2019a; Patrick & Borrego, 2016; Patrick et al., 2018), possibly due to the strong empirical evidence that supports it (Morelock, 2017). Carlone and Johnson's (2007) qualitative investigation of professional women of color found that performance, competence, and recognition were core aspects of science identity. Hazari, Sonnert, Sadler, and Shanahan (2010) expanded on their work by evaluating Physics identity of college students. They found both that performance and competence involve similar behaviors for engineering and non-engineering students, and that interest was an essential aspect of an engineering identity (as indicated by choice of engineering as a major). Their research resulted in a modified three-fold model (Performance / Competence, Interest, and Recognition [PCIR]) that has proven widely useful in understanding student persistence in, and choice of, engineering as a major (Patrick & Borrego, 2016).

It should be noted that while the literature broadly supports these three vectors as central to engineering identity, the literature has not yet solidified on clear predictors of this identity, nor on its impact on student development. For example, Patrick et al.'s (2018) quantitative cross-sectional study cast some doubt on the impact of engineering identity on persistence, once components of the PCIR model were considered. This type of uncertainty is characteristic of still-developing fields (Borrego, Foster, & Froyd, 2014). In sum, the cumulative effect of the engineering identity literature affirms the PCIR model as important to the field, even if the precise boundaries and possible developmental aspects of the model have not yet solidified.

2.1.5.1. Engineer Heterogeneity. It seems a large swath of literature has explored how engineers (and engineering students) differ from others; on the other hand, substantial literature has also explored the varied ways in which engineering students differ (e.g., Faulkner, 2007; Fleming, Smith, Williams, & Bliss, 2013; Tonso, 2007). Inevitably, this leads to a more heterogeneous and dynamic approach to engineering identity, as various facets of the engineering community emerge. In fact, Stevens (2008) suggested that using regression analysis to understand engineering student behaviors or experiences is fundamentally flawed due to its reductionist nature: it assumes that variables make decisions, rather than students. Hence, an accurate and insightful examination of engineering students must respect the complexity of the landscape. For example, Faulkner's (2000) early ethnographic work found three main dualities that existed within technical professions: technical vs. social; specialist vs. heterogenous; and abstract vs. concrete. By exploring these dualities from a perspective of gender duality,

she identified ways in which the engineering culture created dualistic hierarchies hurtful to women. In addition, this hierarchy leads to a preference for certainty over complexity, utility over expression, and technical over social-- resulting in solutions that are technically solid, but possibly lacking elegance and integrative coherence. Later, these dualities were combined to highlight the influential difference between technical and social aspects of the engineering profession (Faulkner, 2007).

Another heterogeneity emerged in Tonso's (2006) study of college engineering students, which identified three types of over-achieving engineers: technicists, nerds, and Greeks. Technicists were motivated by grades, positive recognition, and demands of authority figures. Nerds were internally motivated by content mastery and generally avoided recognition. Finally, Greeks were primarily interested in social aspects of college, such as sports, leadership, and recreation. These categorizations provide insight into how engineering students often distinguish themselves.

The final influential way in which engineering students differ pertains to student development, especially in terms of their progress through the curriculum; in other words, lower-division students take different developmental steps than upper-division students (e.g., Godwin & Lee, 2017; Kurfiss, 1988; Moore, 1994). For example, certain overachiever (technicist and Greek) engineering students often assume more visible and powerful positions by the end of their college careers, even if their technical competence remains inferior to their nerd counterparts (Faulkner, 2007). Godwin and Lee (2017) found that engineering identity overall strength dipped in the second year, then increased until graduation. This dynamic is complicated by the nature of undergraduate

curriculum, where more closed-ended, fundamental topics dominate the lower-division curriculum, and more open-ended, practical activities populate the upper-division curriculum. Not only does this lead to different ways of approaching problems, but it also means that lower-division engineering students spend most of their time learning math and science topics in a classroom setting removed from the engineering discipline, leaving them relatively isolated from authentic engineering content (Meyers, 2009, p. 35). On the other hand, the apparent sophomore slump may be a temporary regression of student perceived performance as part of healthy development (Godwin & Lee, 2017).

Regarding possible developmental influences, two studies have explored how the PCIR model might be influenced by student class level in college. Godwin and Lee (2017) used cross-sectional data of lower-division through upper-division students to explore how Performance, Interest, and Recognition in engineering shifted over the years. In addition, they surveyed students on engineering identity and intent to enter engineering as a profession. They found that all factors (besides Interest, which did not have significant changes) changed from early in college to later: Upper-division were higher than lower-division students, and Sophomores had the lowest scores. The second study was conducted one year later and was also cross-sectional in design (Patrick et al., 2018). This research found that student class level was the strongest predictor of intent to enter engineering as a profession, but not a significant predictor of engineering identity (though the logistical regression effect size was substantial). In addition, they found that Interest and Recognition were the strongest predictors of engineering identity. However, their

research did not explore interaction effects between class level and other independent variables (Patrick et al., 2018).

In summary, the literature suggests that aspects of this model change significantly as students proceed in their college program, but a coherent picture of the ways in which they develop-- especially as a unique group of college students-- has not yet congealed. Hence, clarifying a developmental process that is key to this model of engineering identity is not yet fully supported by the literature. However, the literature on this model widely supports the view of three central factors in one's engineering identity: Performance / Competence, Interest, and Recognition.

2.1.6. Leader Identity Lens

The study of leadership has morphed throughout the history of human civilization. From the earliest times of western civilization, Plato's Republic paints the picture of the impact that an educated cadre of guardians might bring to a society (as opposed to the mob-like rule democracy might cultivate) (Plato, ca. 375 B.C.E., trans. 1952, Books II-IV). More recently, the industrial revolution shifted the locus of social power to corporations—and those leading them. This shift helped create the scientific management field and an increased interest in leadership in spheres outside of politics (Birnbaum, 2000). At the beginning of the modern era, ideal traits of a leader were prescribed (such as eloquence and charisma), following the thinking of antiquity. But this seemed overly rooted in one's inherent nature, as leaders clearly develop. In response, leader behaviors became important (French & Raven, 1959), such as providing support and casting vision (Antonakis, Cianciolo, & Sternberg, 2004, pp. 6-7). But these

superficial behaviors largely work only in the short-term under simple conditions (David V. Day, Fleenor, Atwater, Sturm, & McKee, 2014, p. 64). Moreover, by focusing on virtues of an individual leader, the collaborative process (and the value of team members who have influenced decisions and direction) is backgrounded, leading to an overly simplistic view of what leadership is in actual practice (Collinson & Tourish, 2015).

The limitations of these approaches have been demonstrated in their outcomes: management courses using these approaches have notoriously high variation in their leadership development effectiveness, leading to doubts regarding the actual contribution of leadership programs (D. B. Collins & Holton, 2004). The leadership literature has continued to argue that simplistic approaches to leadership development are common, yet they are relatively ineffective (Dugan, 2011). This concern has been repeated in the engineering leadership literature, where programmatic impacts on leadership development were small compared to curricular experiences (Knight & Novoselich, 2017). To address these historical shortcomings, current leadership theories leverage a plethora of complex developmental concepts from the fields of sociology, psychology, business, and education that focus on the system and processes that drive leadership activity (Snook, Nohria, & Khurana, 2012). For instance, multiple leader behaviors, based on context, came into vogue (Bass & Avolio, 1994). This approach has the ability to describe good leaders. But it leaves unanswered how they got there (Lord & Hall, 2005, pp. 591-592, 596). More recently, Schulman's (2005) signature pedagogies concept has been applied to leadership studies. But this approach merely describes common leadership instructional strategies, rather than "...delv[ing] into the quality of

their impact, effectiveness, and student learning outcomes" (Jenkins, 2012, p. 20). In fact, even the fields of leadership and leadership *development* diverge substantially, because of the complicated nature of leadership development. In other words, leadership *theory* (what a leader is) has less overlap with leadership *development* (how a leader and leadership develop) than what one might intuitively infer (David V. Day et al., 2014).

The difficulties inherent in describing how leaders develop have been increasingly addressed by literature, especially using an identity framework, per Figure 6 (Epitropaki, Kark, Mainemelis, & Lord, 2017, p. 88). Identity provides a lens that addresses complexities such as staged growth, multiple analysis levels, and individualized meaning making (e.g., Hibbert, Beech, & Siedlok, 2017; Hogg, 2001).

Before proceeding, it is worth distinguishing two terms: leader and leadership. As scholars increasingly appreciated the relational aspect of leadership, they distinguished between the individual *leader* and the process of leader*ship* that might be exercised (possibly by multiple leaders) in a group in order to move towards a common objective (e.g., David V. Day et al.; Lord & Hall, 2005). Hence, this research will use *leader* to describe an individual and an individual's characteristics. Conversely, it will use leader*ship* to describe the process whereby a leader (or multiple leaders) exercises influence on, or power over, other group members.

2.1.6.1. Leadership Identity Development Model. One model that has emerged in the literature is the Leadership Identity Development (LID) model (Komives et al., 2009; Komives et al., 2006; Komives et al., 2005). This 6-staged model of relational leadership traces the progression of an individual as they become increasingly aware of leaders until

they are comfortable stepping into leadership roles when the situation warrants (Figure 8). Under this model, those transitioning from a positional to a relational view of leadership—often college students—benefit from learning the language of leadership. Positional leadership is where an individual holds authority to assign responsibilities, make decisions, and take action—often with an elevated title or position. Relational leadership, on the other hand, consists of "…people together attempting to accomplish change or make a difference to benefit the common good" (Komives, Lucas, & McMahon, 1998, pp. 21-22). This transition (from Stages 3 to 4, called Differentiation, Figure 7) is characterized by realizing the conditionality of leadership and how it is not bound to position. Differentiation is especially important for those in autonomous professions (such as engineering), as influence is derived less from position than from expertise (French & Raven, 1959). Individuals furthermore move through Stage 4 (towards Stage 5) as they realize the importance of cultivating future leaders for the sake of a group's larger vision. Komives et al. (2005) suggested that scaffolding of leadership

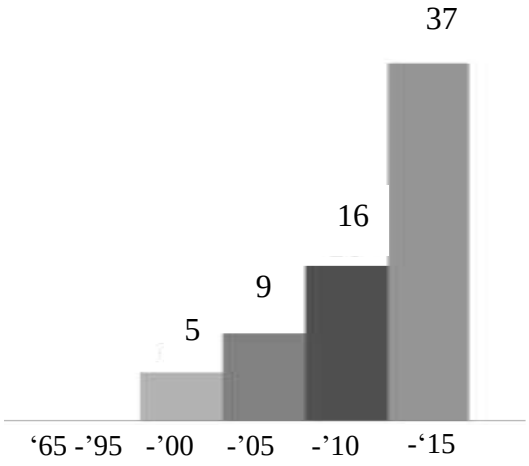

Figure 6. Leader identity and development article count. Vertical axis indicates frequency count of publications on leadership development and identity. Histogram bins designate 5-year increments and all articles before 1995.

theory and helpful collaborative techniques help students in their growth during differentiation. Finally, holding leadership positions—especially in authentic projects--seem instrumental in developing an interdependent view of collaborative work.

The developmental influences by which individuals move through the six stages of leadership are five-fold (Figure 8). First, *Developmental Influences* impact students broadly, often in dynamic ways (e.g., adults first recognize potential and later functioned as meaning-makers). Second, *Developing Self* characterizes experiences that effect

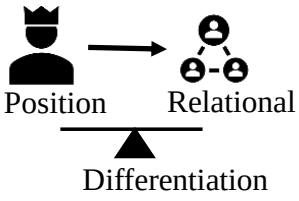

Figure 7. LID differentiation.

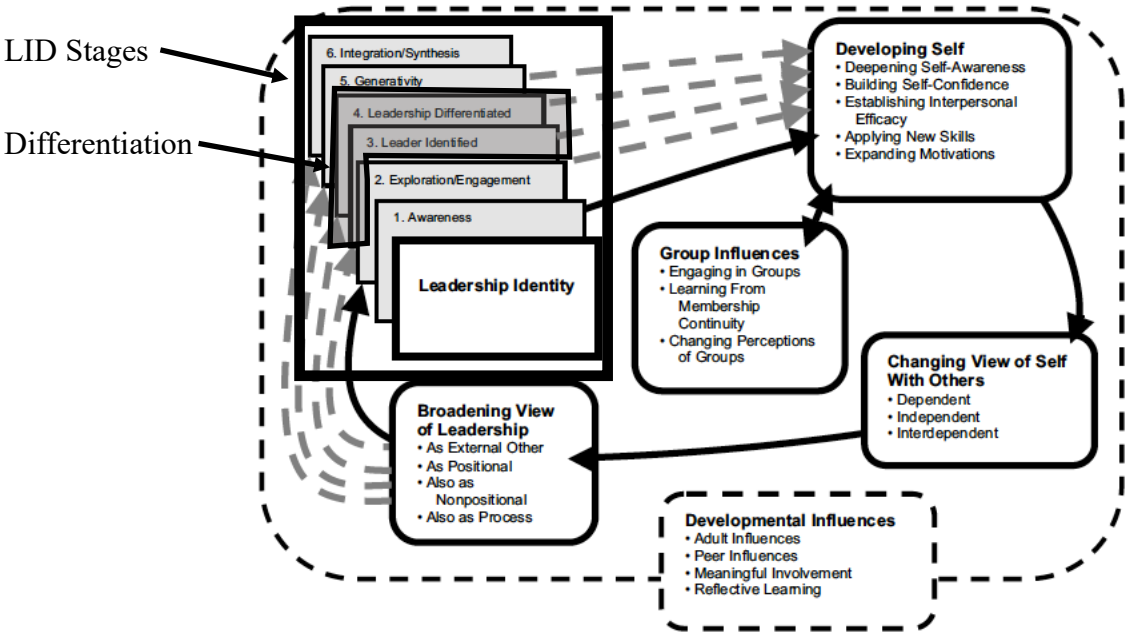

Figure 8: Leadership Identity Development Sources (Komives, Longerbeam, Owen, Mainella, & Osteen, 2006)

personal growth (e.g., building self-confidence and establishing interpersonal efficacy). Third, *Group Influence* includes interactions that are group based (e.g., engagement). Fourth, *Changing View of Self* captures the development of students from being dependent on others to being independent from others to being interdependent with others. Fifth, *Broadening View of Leadership* captures aspects of development pertaining to more expansive thinking about leadership (e.g., leadership as process). The cumulative effect of these influences and experiences is to cultivate leader identity growth.

2.1.7. Summary

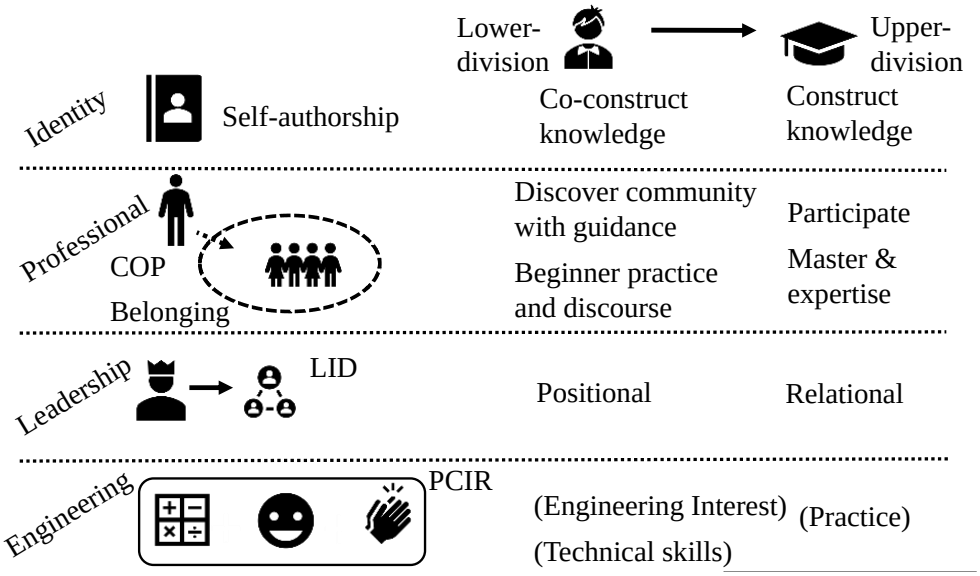

Figure 9. Identity development summary. Parenthetical descriptors indicate characteristics that are suggested, but not established, by the existing literature.

2.1.7.1. Four Adjoining Identity Fields. In summary, the frameworks adopted from these four adjoining identity fields provide a context for understanding engineering leader identity development. A summary of the core concepts of, of the developmental processes for, and of the relationships between each field is in order (Figures 9 and 10).

First, the personal identity provides a context for understanding self-authorship, a central developmental process during the college experience. This process explains how typical lower-division students move from co-constructors of knowledge to constructors of their own ways of making meaning. Self-authorship relates to the Leadership Identity Development (LID) model along several dimensions. Specifically, self-authorship explains the processes of learning to trust oneself and acting on one's environment effectively (in either technical and / or interpersonal fields). These processes support the Developing Self (self-confidence and interpersonal efficacy) and Changing View of Self (independence) LID developmental processes. Trusting oneself empowers one to take responsibility and act independently; acting on the environment effectively is essential to working effectively with others. Moreover, self-authorship relates to self-confidence in one's technical and / or interpersonal skills—essential components of Developing Self and Changing View.

Self-authorship also relates to professional identity, using the Community of Practice (CoP) model. Self-authorship empowers one to direct one's own life and maintain one's own identity: these processes involve shifting the locus of control of one's life from external to internal. This shift in control is what characterizes movement from Legitimate Peripheral Participants (LPP) to more central roles in the profession. Moreover, aligning one's own values with those of the profession is an important mode of belonging. Of course, engaging in more central communal roles is another mode of belonging. Finally, meaning making is an important step within this model, since it describes how students exercise agency by independently pursuing belonging with the

professional community. Students move from discovery of the community and beginner practice to participation and expert-like behavior within the community.

Professional identity may be more specifically explored by looking at engineering identity literature. The Performance / Competence, Interest, Recognition (PCIR) model was used to describe pillars of engineering identity. This model reflects those specific mechanisms by which engineers cultivate belonging and gain status within their respective professional community. According to the PCIR model, students develop from diffuse professional interest and focus on gatekeeping skillsets to aligned values and practicing authentic engineering tasks.

In addition, the LID model relates to engineering identity. The LID model centrally locates the differentiation process. During this process, students move from a positional to relational perspective of leadership. For engineering students, this transition is critical both to understanding leadership within a professional context and to

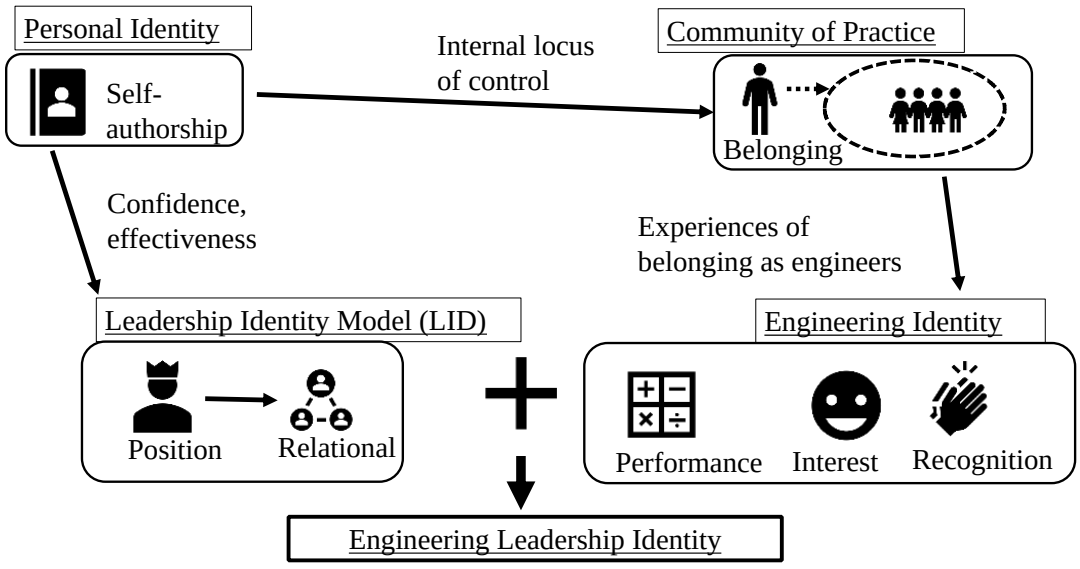

Figure 10. Identity fields summary.

developing appropriate leadership understanding as beginners in this sociotechnical discipline.

In sum, these lenses provide a cohesive insight into developmental processes critical to engineering student education. Confidence, effectiveness, and autonomy are core components of self-authorship. These characteristics support self-development within the LID model. Moreover, when focused on one's professional life, they empower students to develop belonging with their profession. The unique values of the engineering profession are echoed by the PCIR construct. Finally, the differentiation process describes the type of leader identity transition that enables engineering students to understand leadership in the engineering profession. Each of these four identity-based developmental processes (self-authorship, belonging, differentiation, and PCIR growth) provides context for an informed exploration of engineering leader identity (Figure 10).

2.1.7.2. Identity Characteristics. Before proceeding to the engineering leadership identity literature, it is worth noting several characteristics that have emerged during the survey of identity: First, identity development is supported by experience (e.g., CoP learning by doing modality). This indicates that growing to see oneself as a certain type of person is not merely a cognitive exercise, but a growth that integrates experience within an interpretive framework. Related, several identity development theories use stages to describe development, such as the LID model's six stages (Komives et al., 2006) and Kegan's evolutionary truces (Kegan, 1982). It is worth noting that staged views need not require sudden, irreversible, digital shifts, but may accommodate slow transitions, reversals, and simultaneous conflicting behaviors or beliefs from different

stages; these frameworks model human characteristics and allow for the complex processes and variables present in human development, including the multiple paths that individuals take. Finally, identity development theories address the reflective nature of identity growth, as individuals learn to define their internal state of being with increased complexity and consistency. In sum, these characteristics provide the context for viewing engineering leadership through an identity lens. A summary of each identity field and its characteristics, developmental processes, and experiences may be found in Appendix A.

2.1.7.3. Summary. In summary, frameworks from personal, professional, engineering, and leadership identities suggest how one might view engineering leader identity. These adjoining fields provide robust and mature theories that enable an informed reading of the existing literature about engineering leader identity. Their relationships may be summarized according to Figure 10. Here, personal identity contextualizes the importance of competence & professional identity. In addition, it establishes the connection between identity facets (or vectors), which come into play in leader identity. Finally, professional identity leads to engineering identity, which combined with leadership in this sociotechnical discipline, orients engineering leadership & an identity approach to developing it. Moreover, three characteristics of identity theories emerged: experienced, staged, and complex. With a foundation of these four fields and relevant frameworks within them, one is prepared to explore and interpret the engineering leadership identity literature.

2.2. Engineering Leadership Identity Literature Review

Now that interpretive lenses have been established from adjoining fields, a review of the engineering leadership identity literature is in order. This phase uses Keathley's (2014) Systematic Literature Review (SLR) process to evaluate existing literature to understand the literature review guiding question: "What are features of instructional approaches or experiences that develop engineering leader identity?"

The SLR consists of several steps. First, methodological decisions were made to meet the needs of the study: details of the SLR method may be found in Appendix B. Second, literature was identified and studied by conducting a scoping study. The relative youth of the field is reflected in the identification of only four sources. Third, eight databases were reviewed, to cover a broad range of related fields and literature formats. Only research in English was admitted. Whenever source documents were not readily accessible, additional searches and resources were used to procure them.

Fourth, search filters were based on three concepts: engineering, leadership, and identity. Specific filter criteria were iteratively adjusted to maintain a high capture rate without an unnecessarily broad set of literature (Appendix C includes final search criteria and staged summary). The capture rate was 90% across all sources. Additional iterations to capture 100% of scoping literature made it adversely sensitive. Both missed scoping sources emerged in other databases, leading to the conclusion that search criteria and database coverage was sufficient. The total number of initial results was 2,371 across eight databases.

Fifth, exclusion criteria emerged during the creation of the final literature set, as the literature review question is served best by the following foci: developmentally focused, student-centered, and based on developing (i.e., non-critical) identity frameworks (See Appendix E for exclusion summary). This process consisted of three stages: initial review, exclusion, and final review. Initial review consists of abstract and title screening. Exclusion consists of eliminating papers from the final set based on a critical reading of the entire paper, even if the abstract indicates relevance. Final review consists of evaluating the final set to ensure classification was accurate and to collect data for analysis (Keathley et al., 2014, pp. 2-3). This analysis provides a cohesive summary of instructional features that develop engineering leader identity.

2.2.1. Engineering Leadership Identity Literature Overview

Four sources resulted from the scoping study. Through subsequent iterative searches of eight databases, 2371 sources were identified. 120 of these initial results were relevant by title. Of those, 69 were relevant by abstract. Exclusion criteria were then applied to these 69, resulting in a final set of 40 papers (all numbers include duplicates). The final review consisted of reading the final set papers (27 of the total 40 results were unique) both to confirm their relevance and to analyze their contents, per Figure 11.

A survey of the final set reveals several publication trends. First, two groups contribute substantially to the body of literature, comprising 13 of the 27 papers in the final set: Troost Institute for Leadership Education in Engineering (ILead) at University of Toronto and Montana State University (MSU). Second, the engineering leadership

identity literature emerged in 2013, with the number of publications slowly increasing annually (Figure 12). Third, the method of the research was assigned as either qualitative, quantitative, or theoretical, as reflected in Figure 13. Fourth, the context of the literature was predominantly amongst students, per Figure 14. Finally, the use of identity theory varied across the literature in a way that was separated into three categories: literature grounded in identity frameworks; literature using an interpretive

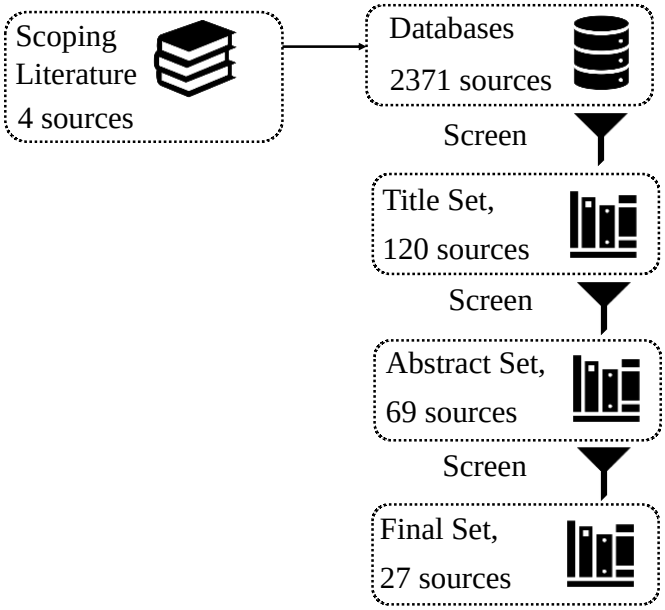

Figure 11. Literature source sets by stage.

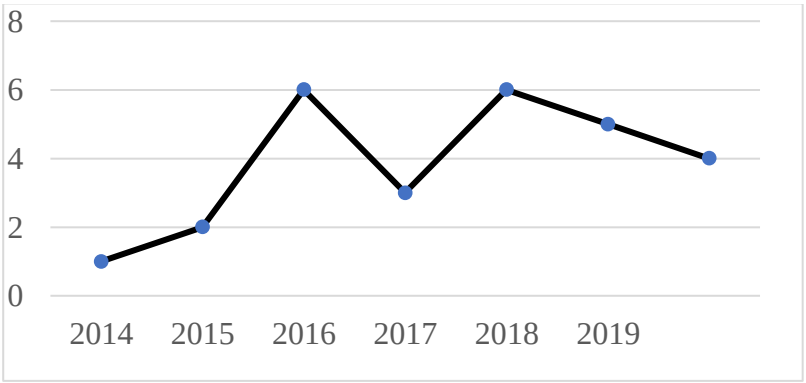

Figure 12. Engineering leader identity article count, by year published.

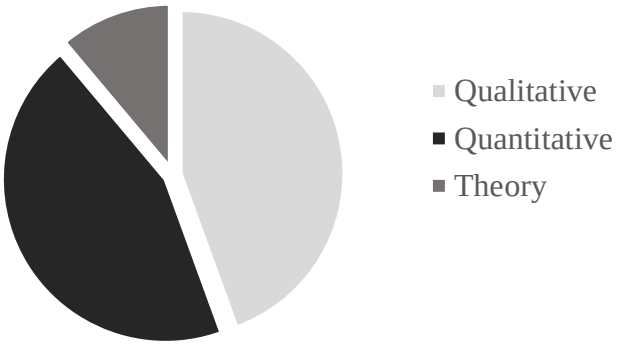

Figure 13. Research method distribution, SLR. Categories are qualitative methods, quantitative methods, and theoretical papers or essays.

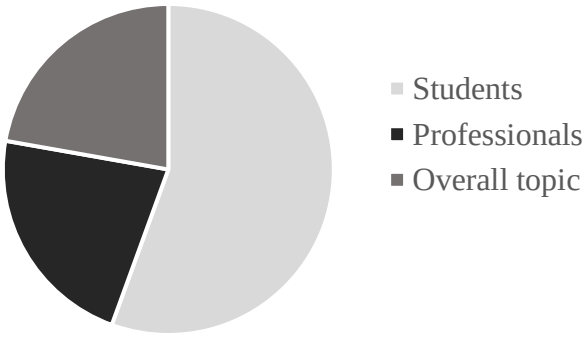

Figure 14. Research participant distribution, SLR. Categories are the context of the research, including overall topical essays or theory.

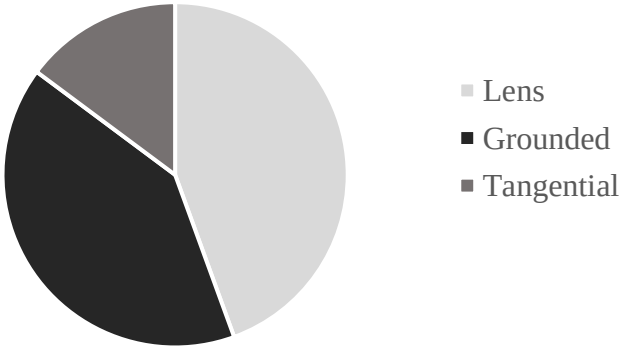

Figure 15. Identity category distribution, SLR. Categories are the ways in which identity is used in the literature: as a grounding for the study, as a lens, or merely tangential.

lens of identity; and literature that uses identity to add some depth to existing findings. Distribution of these uses of identity may be found in Figure 15.

2.2.2. Scoping Set

Identifying scoping literature was the first step in this process, resulting in four sources: Racine (2015), ILead (e.g., Rottmann et al., 2015), Rosch (2016), and Montana State University (MSU) . The relative youth of the field is reflected in the relatively low number of scoping literature sources (as well as in the full literature results). Moreover, these four scoping resources outline much of the field's findings and require detailed summary. An overview of these sources may be found in Appendix D, including findings, theoretical lenses, and relevant learning experiences.

2.2.2.1. Racine.

Racine's (2015) qualitative look at new leaders in the STEM profession used a grounded theory method to gain insight into the formation of these individuals as leaders. Racine leveraged two extant theories to contextualize his findings. The first was Robledo's Three Vector Model of Scientific Leadership, which outlines the roles of a STEM professional as involving individual technical work, the group, and the organization (Robledo et al., 2012). The second was Social Identity Theory (McKeown, Haji, & Ferguson, 2016), which says that the relationships between the self, peers, and the discipline impart belonging to the group. In particular, "[t]he 3-Vectors Model of Scientific Leadership defines the situation where the experience is demonstrated. Social Identity Theory provides a basis for the interconnectedness of relationships needed for leadership success" (Racine, 2015, p. 25). Three scoping characteristics emerged from this research: technical competency was the foundation for leader success; engagement

with leadership changed leader behavior to focus on the Group vector; and demands for professional proficiency changed with the assumption of a leadership position. Finally, Racine proposed several reasons why autonomous professionals may find leadership problematic, mostly focusing on the inherent tension between leading others (for project progress) and autonomy (an inherent characteristic of technical professionals).

To best support the development of new STEM leaders, Racine (2015, pp. 36-37) suggested several practices:

1. mentoring (especially in terms of scaffolding prototypical behaviors and explaining the complexities of organizational dynamics),
2. practice in low(er) stakes environments,
3. group-work skill training (such as cooperation and in-group favoritism),
4. basic social skill training (especially pertaining to building healthy relationships), and
5. feedback on sociotechnical performance.

While these findings are largely transferrable to the university setting, it is worth noting that the research was on STEM professionals, rather than just engineers; the sampled population consisted of professionals rather than students; and (possibly most importantly) leadership was viewed exclusively from a positional perspective

2.2.2.2. Troost ILead. This leadership institute at University of Toronto has grown extensively since its founding in 2010. It has grown both as a training ground for sound engineering leadership education and as a prolific source of engineering leadership research. Hence, this literature review will group literature from ILead researchers in the

interest of simplicity. The second scoping literature source was a grounded theory that researched leadership as a component of engineering identity by qualitatively exploring professional leaders (61 Canadian professional engineers) (Rottmann et al., 2015). This research made three contributions: engineering leaders were perceived along three constructs; engineering resistance to leadership was not universal; and several practices were recommended to build leader identity. The three orientations professional engineers had towards leadership were technical mastery, collaborative optimization, and organizational innovation. "Engineers generally take one of three approaches / constructs to leadership-- They shared their well-developed technical problem-solving skills with others through informal mentorship—*technical mastery*; they built effective and efficient teams across organizational units by learning about and leveraging their colleagues' strengths—*collaborative optimization*; and they used entrepreneurial thinking to bring technically sound ideas to market—*organizational innovation.* "We refer to these three distinct constructs of engineering leadership as constructs to highlight their developmental rather than deterministic nature." (Rottmann et al., 2015, pp. 7-8). Technical mastery was most common with early career professionals, and it reflected a craftsmanship approach to the profession. Collaborative optimization was the most discussed leadership construct, where leaders were motivated to deliver a quality product. Finally, organizational innovation was most commonly associated with late career and management professionals, with a focus on vision and the strategy required to fulfill it. This three-fold approach has echoes in other leadership literature, suggesting that these

findings may be widely transferrable (Appendix F) (Hogg, 2001; Racine, 2015; Robledo et al., 2012; Rottmann et al., 2015).

This ILead research also identified differences between those resistant to leadership and those who embraced it. Those resistant to leadership held on to charismatic and influential notions of leadership, typical of more primitive trait-based theories. They often perceived the values of a leader as being opposed to those of an engineer (e.g., dynamic, influential, charismatic). Moreover, they saw the engineer's role as primarily that of obedient technical problem-solver (i.e., 'do what you are told'). On the other hand, those engineers who embraced their leadership roles saw engineering going beyond technical problem solving; the leader was a coach, servant, or inventor. For example, organizational innovators used the vision of an "imagined future" to motivate and influence others, rather than "charismatic personality" (Rottmann et al., 2015, p. 14). And engineering leaders were perceived as "doers," rather than (the traditional notion of leaders as) directors. This latter category of engineers showed little resistance to embracing engineering leadership.

Finally, this literature suggested several developmental practices that might support engineering leader identity growth (Rottmann et al., 2018; Rottmann et al., 2015). First, they suggested not using the term 'leadership' when introducing students to the topic, due to the unfavorable connotations that many engineering students may have towards it. Other terms, such as responsibility, vision, and collaboration were preferred. Second, they suggested normalizing influence (in terms of technical capability or creative vision)

as a dispositional characteristic rather than a positional one. This might make small leadership practices more accessible to those who do not yet see themselves as engineering leaders. Third, they suggested talking about the collaborative and interpersonal characteristics of the profession. By talking about leadership in terms of professional values and function, instructors may be able to interrupt the communal dichotomy between technical and social skills. This literature source effectively described how leadership is operationalized in the profession. More, it did so in terms of professional values, which provide the engineering student an opportunity to "…recogniz[e] themselves as members of a leadership profession" (Rottmann et al., 2015, p. 1).

2.2.2.3. Rosch. The third scoping literature is based on leadership development in bioengineering courses at University of Illinois Urbana-Champaign (Rosch, 2015; Rosch, Collier, & Zehr, 2014; Rosch & Imoukhuede, 2016). The largely quantitative exploration of engineering leadership development measured various aspects of leadership growth during project-based courses. Their initial work (Rosch et al., 2014) found that one's inclination to lead (due to responsibility to the team) marginally increased over the semester. They also found that seeing oneself as a natural leader, as measured by the Motivation to Lead, Affective-Identity factor (Chan & Drasgow, 2001), was the most powerful influence on others seeing oneself as a leader. To improve the effectiveness of group work, they suggested long-term goals, peer feedback, and interdependent group roles. (Rosch et al., 2014, pp. 112-113).

In a follow-up article one year later, Rosch (2015) found minimal leadership growth over the course of a semester in a project-based course, in terms of motivation to lead, leadership behaviors, and leadership self-efficacy. He summarized that "…simply placing students into teams, in which they possess motivation to succeed and must act interdependently, may not be enough to accelerate the development of their leadership capacity " (p. 113). Recommendations for effecting student leadership growth were threefold. One, allow and support intentional practice in leadership activities. Two, scaffold leadership-focused team forethought activities (such as determining guidelines for group behavior) and reflection on recent leadership experiences. Three, provide digestible teaching on group skills, such as conflict management, decision-making, and cross-cultural understanding.

These two studies informed Rosch and Imoukhuede's (2016) quantitative research on improving leader identity and motivation. The main focus of their semester-long intervention was leadership training, combined with curricular sessions of leadership practice towards a final project. In addition, a team homework assignment addressed technical issues through a social issue lens. Furthermore, they integrated leadership skills awareness (Clifton Strength Finder). Finally, several additional practices intended to support effective teamwork: rotating team rolls, Comprehensive Assessment of Team-Member Effectiveness (CATME)-informed team assignments, addressing individual characteristics (e.g., fraternity membership, gender, GPA, software skills) in team assignments, and delivering a final project (with interim reports).

The findings from this research are particularly relevant to engineering leadership development. They found significantly better growth in leader identity over the semester, but marginal growth in motivation to lead. Moreover, reflection, practice, and scaffolding were essential for team-based practice to achieve full impact in developing leader identity (compared to a control group). This research was able to use reflection, individualized skill training, rotating roles, group work, and strategic team assignments to reflect 'best practices' in engineering leadership instruction. While this is a promising path, leadership was framed more in terms of skills and behaviors, rather than an essential aspect of the profession (which would align with a COP approach). Moreover, they did not explore students' definition of leadership, leaving it unclear the type of leader with whom students were increasingly identifying. It should be noted that they used a retrospective post-survey that included BEFORE and NOW components to identify perceived growth. In retrospective surveys, participants are asked about their beliefs on something before an intervention (BEFORE); they are subsequently asked about their belief on the same thing presently (NOW).

2.2.2.4. Montana State University. The final scoping research on engineering leadership comes out of a continually unfolding literature stream from Montana State University (e.g., Hughes, Schell, & Tallman, 2018a; Hughes, Schell, & Tallman, 2018c; Schell, Hughes, Tallman, Kwapisz, et al., 2019). The main literature used for the scoping review is the proposal of a grounded theory approach to engineering leader identity, with the intent of understanding engineering students' leadership development (Schell & Hughes, 2017a). Their initial work uses the LID model to contextualize leader identity

development, and it uses the CoP model to contextualize professional identity. Their quantitative and qualitative analyses consist of seven publications used in this review, as well as several other published and not-yet-published articles (articles published after August 2020 are not included).

Due to the close connection between the grounded theory proposal and the findings that are emerging from MSU, the summaries of their findings are included here (rather than in the fuller literature findings). Their preliminary quantitative (Hughes, Schell, & Tallman, 2018b; Hughes et al., 2018c; Hughes, Schell, et al., 2019a, 2019b; Hughes, Schell, Tallman, et al., 2019; Schell & Hughes, 2017b; Schell, Hughes, & Tallman, 2018a, 2018b, 2018c) and qualitative (Annand, Kwapisz, Tallman, Schell, & Hughes, 2019; Hughes et al., 2021; Kwapisz et al., 2019; Schell, Hughes, Tallman, Kwapisz, et al., 2019; Tallman et al., 2019) work on an engineering leader identity grounded theory has provided some insight into its development. They found that interacting with diverse others was an impactful experience for developing 'professional' leadership skills. They also found that authentic experiences outside the classroom were helpful in developing more 'technical' skills (e.g., critical thinking or solving problems) (Schell et al., 2018c; Schell, Hughes, Tallman, Kwapisz, et al., 2019). Their qualitative research found that student perception of engineers broadened substantially as they began their degree program, but how they saw engineering varied a lot between students (Hughes et al., 2021). Second, the research demonstrated that authentic group experiences were instrumental in becoming engineering leaders, especially in terms of group skills and confidence (Hughes et al., 2021). Participants expressed that authentic

experiences and peer recognition were important in their self-schema as engineers and leaders. However, engineering identity development seemed linear, unlike leader identity; and different skills were required for the two identities (Schell, Hughes, Tallman, et al., 2020). Yet, one of their earlier papers suggested that stronger engineering identity correlated with a stronger leader identity (Schell, Hughes, Tallman, Annand, et al., 2019). Finally, the types of terms used to describe leaders versus engineering leaders varied. Expertise, communication, skills, and big picture thinking were relatively common to leaders and engineering leaders. On the other hand, more rational terms were associated with engineering leaders (e.g., problem solvers), but more emotional terms were associated with leaders overall (e.g., inspiration) (Schell, Hughes, Tallman, Kwapisz, et al., 2019).

2.2.3. Final Set Overview

The final literature set was summarized according to main findings, listed instructional strategies, methods, population, and other variables to characterize the results. Appendix G provides an overview of this literature, key findings, and theoretical frameworks. To summarize the literature cohesively, it was reviewed for trends based on article characteristics. How identity was used in the research emerged as a useful categorization: Grounded in Identity, Identity as Lens, and Identity Tangential. Grounded in Identity describes research that is based on an identity framework; Identity as Lens describes research that interpreted results using identity theory, even if the overall research approach was not based on identity; Identity Tangential describes

research that is not explicitly identity-based but meaningfully contributes to this research, nonetheless.

2.2.3.1. Grounded in Identity. The studies most fully grounded in engineering leadership identity are those that used an identity-based framework for the entire study, in terms of measures, study intent, and study structure. While using an identity lens to interpret results is helpful in interpreting responses in some situations (e.g., developmentally complex processes), an identity framework as part of the research design provides a coherent approach to effecting and interpreting participant response. In fact, this type of literature most directly addresses the purpose of the literature review, by foregrounding identity. These 11 articles included mostly qualitative research (7/11) and the four scoping articles. Four of the articles reported on engineering students, including Rosch's research of bioengineering students and two of the articles coming out of MSU. The fourth evaluated leadership skill during entrepreneurial instruction in a upper-division design course, finding that students reported a higher inventor identity than founder or developer identity (Edwards Jr & Pillapakkam, 2018). This work-in-progress theorized that entrepreneurial instruction that included scaffolding, feedback (via mentorship), and basic concepts of entrepreneurship would influence entrepreneurial identity, but final longitudinal results of this research are not yet published.

Four additional articles using an identity framework explored engineering leadership in the professions. Two of these were scoping articles (Racine, 2015; Rottmann et al., 2015). A third article emerged from the ILead group that explored influential experiences for leader formation of early career professionals (Klassen et al.,

2017). They used Ibarra's (1999) provisional selves theory to frame qualitative inquiry of participant identity, finding that project management and mentorship were most influential to identity. They recommended five practices that might cultivate leadership in a professional context: build relationships (especially regarding diversity and empathy), reflection in partnership with feedback (possibly from mentors), authentic learning (self-directed, challenging, and open-ended), optional workshops, and expanding scope of work. It should be noted that they used a 5-vector model of leadership skills instead of a leader identity lens. A second article explored the motivation to lead among engineering managers (Ulrich, 2017). The author found that motivation to lead was mixed amongst the six participants. He suggested that leadership must be first contextualized in terms of professional values; in other words, engineers must first be convinced that leadership is positive, possibly by phrasing it in terms of team needs. He also found that mentorship (or influential individuals) was an important factor in many leaders' development. Finally, he suggested several approaches to improve managers' comfort in navigating social situations. However, it should be noted that this study depends on a positional view of leadership and that the suggested practices are inferred from participant reports of their own experience, not grounded in empirical evidence.

Finally, three articles using an identity framework explored the topic from a global perspective, including the scoping article from MSU. In addition, authors from ILead published findings from a symposium of engineering leadership, integrating professional, organizational, and individual units of analyses (Rottmann et al., 2018). They described two emergent tensions particularly relevant to the engineering leadership

development: position vs. process (leadership) and situated vs. formal (education). While identity was core to their work, the explicit framework was Community of Practice (CoP). They suggested five practices to further engineering leadership within a CoP framework: integrate social issues in curriculum (possibly through case studies), offer challenging group projects, provide environment to experiment with leadership skills, and reflection on workplace incidents in academia. The second article was a qualitative exploration of high-achieving high school students (Couch, Skukauskaite, & Estabrooks, 2019). This article is included here because the research examined at engineering and leadership as independent identities, which gives a global view of how those entering college think of them, while not truly studying engineering leadership itself. Their research took a Social Identity approach, where an individual has multiple emerging aspects. They found that participants increased self-identity in engineering and leadership after summer project-based inventing camp. The camp consisted of authentic team projects that served the community, guided by mentors. However, the population was high school students, hence perceiving oneself as an engineer may not be representative of the perspectives of college engineering students. And the connection between engineering and leadership identities was not explicitly explored, but incidental.

2.2.3.2. Identity as Lens. The next group of articles used identity as a lens to interpret research findings, though identity was not a central component of the study design. The clear majority (10/12) of these articles addressed student populations, while the remaining two addressed professionals. The MSU research group consisted of four quantitative explorations of students (Hughes et al., 2018b; Schell et al., 2018b, 2018c).

The remaining six references included two that explored identity implicitly, three that used an identity lens for interpretation of results, and one that took a critical approach.

Two researchers explored identity implicitly, by exploring student self-report and reflection. The first of these was Ahn's (2014) quantitative research to create an engineering leadership assessment. He asked students to self-report how they embody leadership according to one of three vectors, taking mostly trait- and behavior-based approaches to leadership. There was little identity framework to justify the study, and the assessment failed to identify differences between upper and lower division students, though differences were suspected (Ahn et al., 2014, p. 130). The second study of student reflection was a qualitative analysis of the impact of a Reflected Best-Self (RBS) approach in the development of engineering leader identity. While the methodology of this research was active research, it used qualitative data gathered over 10 years—moreover initial findings seemed to connect reflection, feedback, and personality discussion with leadership growth amongst engineering students (Nino, 2016).

Several researchers evaluated engineering leadership development through an identity lens. Knight and Novoselich (2017) quantitatively explored the impact of curricular and co-curricular activities on leadership development, finding that curricular influences were strongest. While they used Terenzini and Reason's (2005) College Impact Framework, they incorporated the identity lens into their analysis of leadership approaches (e.g., viewing leadership as a professional value (Knight & Novoselich, 2017, p. 62). They found that group learning was a powerful instructional approach for leadership self- rating, and that co-curricular engagement was not as influential.

However, while the variable of interest was a self-assessment, it was based on specific traits and behaviors rather than deeper beliefs or values regarding leadership. Moreover, their analysis looked at structural influences without further exploring conditionality (i.e., well-executed and poorly structured group activities were not differentiated).

The second article used an identity lens to qualitatively interpret Peer Leader of Learning Teams (PLTL) experiences (E. C. Johnson, Robbins, & Loui, 2015). A cognitive apprenticeship framework was used to support leadership development. They found that thinking critically, reflecting on learning, and appreciating diverse perspectives were influential for cultivating leadership confidence. In addition, group learning environments were central to the research. And, scaffolding and instruction on effective leadership behaviors were provided to leaders throughout the project. However, the authors did not explore follower development or peer leader identity growth. The third article to use an identity lens also evaluated the developmental effects of an approach that paired older leaders with introductory students (Montoya et al., 2015). These second-year students, called Mavericks, helped redesign and implement the curriculum for an existing introductory course. They found that leaders involved in this course showed a stronger personal identity and higher problem-solving skills. By viewing identity as who they are and who they want to become, the researchers concluded that experience-based learning, reflection, and mentoring others (especially through informal connections) were valuable for leader identity development. However, the lower-division students were only anecdotally described, and the methodology was active research (Montoya et al., 2015).

One quantitative study of engineering leader identity took a critical approach to the identity lens (Serrano & Groh, 2016). They found that women engineers who attended a leadership conference reported growth in several engineering leadership components. While the measures were not validated and included only 27 participants, the results are promising for students engaged with the profession as undergraduates. The authors suggested that targeted events can positively impact personal and professional identity for under-represented minorities. Targeted events may provide context for leadership in terms of professional values, thereby leading to increased motivation to lead. They may also benefit students by outlining leadership ideas in more detail, thereby leading to increased understanding of leadership ideas and behaviors. Small sample size, self-selection bias, and the source of the perceived identity growth were limitations to their study.

Two remaining articles explored a professional environment, taking a positional view of leadership. The first quantitatively explored defensiveness differences between engineering and non-engineering managers (Riley, Cudney, & Long, 2013). They found no quantitative justification for engineers being more defensive. However, they agreed with the literature showing that engineering students are ill-equipped to enter organizational environments compared to their non-engineering peers (p. 50). Hence, they suggested leadership training for engineering managers: scaffolding via role-playing that promotes healthier leadership framework or leadership skill training. They also suggested that social skills may be advantageous in developing certain healthy leadership approaches. The second resource was a qualitative exploration of professional women

scientists (West, 2017). While the participants were not engineers, this article was useful in its exploration of leader identity in autonomous professions. The authors found that mentoring, reflection, social capital, peer learning, self-efficacy, and value-based purpose were beneficial for leadership development.

2.2.3.3. Identity Tangential. The third category of literature used identity only tangentially, yet it contributed to the literature review purpose. Two of these sources thoroughly evaluated engineering leadership programs. The first reported on the ILead program in terms of self-schema and identity facets (i.e., self, team, organization, society) (Reeve et al., 2015). Reeve and his colleagues wrote this paper as a case study on their leadership program using four levels of analysis (self, team, organization, and society). Amongst their many findings, they foregrounded the importance of reflection and experiential learning in many of their programmatic features. The other program evaluation summarized fourteen engineering leadership programs (Klassen et al., 2016). They took a holistic view of leadership pedagogies and approaches that clarify the many ways that leadership may be seen. This view highlights the individualized path of leadership, which aligns with identity approaches. They found many features that were part of successful leadership programs: reflection, authentic learning, group work (especially across disciplines), increased understanding of leadership theory, the importance of leadership to professions, and social skills. However, identity was not an explicit or central focus of either of these articles, and the nature of a show-and-tell approach introduces severe limitations to the findings. Another article explored the

identity development of several undergraduates, as they participated in leadership research: it was included in the MSU literature summary (Kwapisz et al., 2019).

Finally, Neeley (2015) argues for responsibility amongst engineers, not only in technical accuracy but also in application of their solutions in society. She suggests that authenticity—here redefined as principled nonconformity, meaning that one is truly independent and able to operate outside of society's demands-- is a central aspect of engineering leadership. While she does not forward this argument within an identity framework, the argument rests on the centrality and strength of one's professional identity and convictions to act in alignment with its values.

2.2.3.4. Summary. This review of the engineering leadership identity literature has identified three broad categories of how the literature uses identity. The literature with the most central positioning of identity uses an identity-based framework to ground the research. This literature, which includes the full scoping set and additional sources, provides insight into engineering leadership development in college and in the professions, providing context for identity theory from adjoining fields. The second category of literature uses an identity lens to interpret engineering leadership (such as the College Impact Framework), predominantly in a university setting. Finally, several articles explore engineering leadership identity incidentally, yet provide valuable insights into the field, such as highlighting the individualized nature of leadership development.

During this process, it was found that the engineering leadership identity literature does not address developmental stages or identity characteristics as robustly as adjoining fields do (e.g., self-authorship, belonging). However, the engineering literature does

provide operationalization of limited aspects of identity and developmental processes. An excellent example is understanding how leadership practice in engineering overlaps with key characteristics of the profession (Rottmann et al., 2015, p. 7). Therefore, using adjoining fields as a lens to understand and explain the engineering leadership literature provides a well-grounded and complex framework through which the literature can be organized.

2.2.4. Features Overview

This section outlines the identity development features that emerged in the literature review. An emergent approach was used to identify common features in the literature. For each literature source, a list of instructional and programmatic characteristics used was outlined. These characteristics were then iteratively categorized using the lenses of the four adjoining fields (Appendix P). This resulted in a categorical structure that is supported by mature theory in fields related to engineering leadership identity. It should be noted that the education literature on these nine instructional characteristics is extensive and well beyond the scope of this research—for example one article alone categorizes reflection into four levels based on depth (e.g., Grossman, 2008). The characteristics and descriptions included here are limited by the scope of the literature review. The interested reader may find much richer discussion and exploration of the instructional features listed here in the education and identity literature.

Following this iterative, emergent process, the scoping and final sets together suggest nine features of student engineering leader identity development. This addresses the literature review guiding question: “What are features of instructional approaches or

experiences that develop engineering leader identity?" The nine features of identity development are the following: Reflection / Feedback, Authentic Experiences, Scaffolding, Peer Learning / Group Work, Differing Perspectives, Tools / Language, Values, Technical Skills, and Social Skills.

2.2.4.1. Reflection / Feedback. Reflection and feedback are impactful mechanisms during identity development. Through them, individuals develop self-authorship: this is accomplished by resolving tension, creating sophisticated meaning-making, and taking responsibility for one's own views. In addition, reflection and feedback enable individuals to assume greater professional belonging (through imagination and alignment), to be recognized as engineers, and to develop complex leadership frameworks.

While both reflection and feedback processes are essential for evaluating and adjusting behavior, reflection functions predominantly within the intrapersonal domain and feedback functions in interpersonal and group domains. The literature tended to focus on reflection or feedback depending on the theoretical framework used, even if the developmental function (as defined here) of the two largely overlaps. An exception to this generalization is a paper on the adoption of a Reflective Best-Self pedagogy, which included gathering feedback from multiple figures in a student's life and using that feedback to reflect on "…your natural talents, skills, and personal values" (Nino, 2016, p. 7).

Reflection was widely used as central components in classroom practices to cultivate identity: it was referenced in over 1/3 of the sources in the literature review. In

fact, every study that adopted a holistic pedagogy-- RBS (Nino, 2016), PLTL (E. C. Johnson et al., 2015), Mavericks (Montoya et al., 2015), and Rosch (2016) (best practices for teaching engineering leadership) found that reflection was of vital importance: it cultivated critical thinking, integration of theory into experience, and meta-cognitive growth. These developments were especially important for engineers to see leadership as a value to the profession and to legitimize more relational approaches to leadership (Reeve et al., 2015). Moreover, reflection may be important for students to move forward through paradigmatic shifts, such as might occur when learning about the complex field of leadership (Kwapisz et al., 2019). Most discussion of reflection addressed student groups, but Klassen at al. (2016) concluded that even professionals would benefit from authentic discussion and reflection, as they struggle to expand their understanding of leadership.

The importance of feedback emerged in four core ways. First, peer feedback provides an avenue for recognition of good work (Carlone & Johnson, 2007). Of course, it is also valuable for technical comprehension, as individuals verify well-structured thought processes or problem-solving. Second, peer feedback builds confidence of those providing feedback and interest in leadership roles (E. C. Johnson et al., 2015), while also providing a source of meaning and support (Atman et al., 2010). Moreover, feedback (regardless of source) is essential for the more complex situations, behaviors, and skills associated with more advanced leadership scenarios (D. V. Day & Dragoni, 2015; Dennen & Burner, 2008; Rottmann et al., 2018). Hence, mentoring—which enjoys broad literature support (Atman et al., 2010; Carlone & Johnson, 2007; Couch et al., 2019;

David V. Day et al., 2014; Klassen et al., 2017; Montoya et al., 2015)—may be classified here, as well.

2.2.4.2. Authentic Experiences. Authentic experiences allow individuals to exercise independence in a meaningful environment, and they form the backbone of situated learning good practices (Lave & Wenger, 1991). These experiences facilitate autonomy, cultivate belonging through engagement, foreground the importance of leadership in a group, and act as a context for engineering interest, performance, and recognition. While two studies of professionals highlighted the importance of self-directed, challenging, open-ended experiences, trial and error, scaffolding, and basic developmental support (Klassen et al., 2017; Racine, 2015), the remainder of the literature highlighting authentic experiences did so in a university context. These studies reported that experience in a meaningful project was a central component of engineering leadership development (Couch et al., 2019; Montoya et al., 2015; Rosch & Imoukhuede, 2016; Schell et al., 2018c). Often, these meaningful projects were encountered outside the classroom, through internships or extracurricular activities (such as club membership). It should be noted that these settings also included some aspect of mentorship or scaffolding to actualize student growth, as quantitatively demonstrated by Rosch (2016).

2.2.4.3. Scaffolding. Scaffolding provides a way to develop more complex frameworks, which is a process at the very heart of identity development (Chickering & Reisser, 1993). This is an essential component of a post-reflective cognitive stance, engagement with an authentic community (especially engineering), and adoption of

relational and conditional leadership. Scaffolding seemed most important to individuals who had already demonstrated leadership behaviors, often in the professions. Case studies (Rottmann et al., 2018) and role-playing (Riley et al., 2013) were two concrete techniques for scaffolding more complex leadership frameworks in engineering. In addition, the importance of prototypicality to the autonomous professional leader suggests that scaffolding may be particularly powerful as a developmental tool for future leaders (Racine, 2015; Van Knippenberg et al., 2005). It is also worth noting that mentors may also use scaffolding to help leaders make sense of complex challenges (Couch et al., 2019; Montoya et al., 2015; Reeve et al., 2015).

2.2.4.4. Peer Learning / Group Work. Peer learning and group work provide a context for clarifying and strengthening one's beliefs, leading to more reflective reasoning; they support belonging and recognition in a professional context; and they lead to responsibility to a shared goal, often through interdependence (which leads to more relational views of leadership). The results of the SLR indicate that these experiences are valuable due to the complex, difficult nature of group work, where definitive solutions and theories are non-existent. Hence, it was not surprising to find that over 1/3 of the literature in the review highlighted the importance of these types of experiences. As a result, learning by doing, especially in a group, is broadly recommended by the literature (e.g., Couch et al., 2019; Knight & Novoselich, 2017; Rosch & Imoukhuede, 2016). Some note its value to developing interest, some to demonstrating expertise, and some to enjoying meaningful work. Moreover, providing a safe environment for trialing various leadership behaviors also provides a learning

opportunity for all (Racine, 2015; Rosch & Imoukhuede, 2016; Rottmann et al., 2018; Ulrich, 2017). However, group work is not a silver bullet; Rosch's (2015; 2014) research found that group environments (such as are experienced in class or upper-division capstone projects) without mentoring, scaffolding, and leadership skills failed to effect perceived growth. Peer learning seems to benefit everyone involved; older peers seem to benefit from the practice as well as their younger peers (E. C. Johnson et al., 2015; Montoya et al., 2015). Finally, group projects were widely reported as the context for impactful experiences during leadership development, even if the conditionality of these experiences is less understood (e.g., Couch et al., 2019; Rosch & Imoukhuede, 2016; Rottmann et al., 2018; Ulrich, 2017).

2.2.4.5. Differing Perspectives. Activities that promote differing perspectives develop more complex overall views of the world, most often through critical reflection: possibly in terms of one's professional alignment or imagination, or in terms of leadership understanding. While the value of seeing others (and the world, overall) from differing perspectives was noted as helpful, especially for leadership development (Klassen et al., 2017; Rottmann et al., 2018; Ulrich, 2017), further details of how this is cultivated were largely absent. This may be due to its inclusion in less than ¼ of the literature, where it was more often mentioned incidentally, rather than centrally. The MSU literature stream has suggested that interacting with diverse others is impactful in developing professional skills (Schell et al., 2018c). Neeley's (2015) work on principled nonconformity, where habits of mind that were rooted in other fields help develop traits

and values important to leadership (e.g., grace, communication, wit), provides another source of the expansion of one's perspectives-- education.

2.2.4.6. Tools / Language. Language is a tool for creating and communicating ideas (Vygotsky, 1986); it is also the medium through which one engages with a broader community (Gee, 2000). Here, tools / language may be understood as communicating about leadership as a field of theory and practice; in other words, simply talking about leadership in an informed way. This might involve exploring different ways of practicing leadership (e.g., Racine, 2015; Riley et al., 2013; Rosch & Imoukhuede, 2016; Rottmann et al., 2015) or re-defining leadership in terms of professional values (e.g., Serrano & Groh, 2016; Ulrich, 2017). Using this definition, language brings clarity to knowledge and values, and it helps mediate recognition (through which belonging is achieved) (Wenger, 1998). The CoP model foregrounds the importance of objects and artifacts that convey meaning and values of a community or profession. Likewise, the LID model highlights the importance of scaffolding and vocabulary in leadership development, especially during differentiation.

The engineering leadership identity literature highlighted the importance of tools / language in continued development of a leader identity. Klassen (2016) noted that almost all existing programs include some aspect of leadership instruction, mainly to support the primary focus of developing student skills and behaviors. Ullrich (2017) and Rottmann et al. (2015) went further by suggesting that programs contextualize leadership within the professional engineering environment. This provides an informed way for students to understand leadership that is more likely to be consistent with engineering values. For

example, Edwards and Pillapakkam's (2018) suggested that basic instruction on engineering leadership (in terms of entrepreneurial thinking) might develop of entrepreneurial leadership. And Serrano and Groh's (2016) research on female student conference attendance connected learning about leadership in a professional setting with several positive outcomes (such as increased interest and self-efficacy). This connection has been noted in the leadership literature, as well: Dugan (2011) suggests that underserved populations may need support in leadership efficacy much more than existing programs provide. Finally, Riley et al.'s (2013) research of engineering professionals suggested that simply understanding healthy and problematic leadership behaviors "…can cause an organizational culture shift in being able to openly discuss issues and not avoid them when they arise" (p. 50).

One noteworthy concept that emerged from several sources was to use the word leadership with engineers carefully, due to resistance to traditional notions of leadership (Rottmann et al., 2018; Ulrich, 2017). Instead, these authors suggested focusing on the professional function and value, thereby highlighting its importance to the profession as well as its sociotechnical nature. In fact, the literature stream coming from MSU initially posited that this resistance may stem from tension between engineering and leadership identities (Schell & Hughes, 2017a, 2017b). Finally, Neeley (2015) expanded the scope of defining leadership in terms of professional values, suggesting that a broad range of cognitive tools and vocabulary are essential to understanding and practicing such a multifaceted topic as leadership, which is an idea echoed by other scholars (Allen & Shehane, 2016).

2.2.4.7. Values. Values lie at the heart of identity, in terms of making meaning (Baxter Magolda, 1998), alignment with a profession (Wenger, 1998), and commitment to a shared vision (Komives et al., 2005). This idea is central to autonomous professions, where a tension may exist between individual responsibility and group mission (Andrews & Farris, 1967; Racine, 2015). Some of the student-focused literature suggests that the values of engineering and leadership may conflict (e.g., Rottmann et al., 2015; Ulrich, 2017). Hence, defining leadership in a professionally relevant way may lead to less resistance to the idea itself (Rottmann et al., 2015). Some suggest that communicating engineering as a sociotechnical discipline is another way to overcome this tension, through exploring technically-based social issues (Rottmann et al., 2018) or highlighting the skills required to work effectively in a group (Rosch, 2015). The most influential literature comes from ILead, where the construct of engineering leadership provide insight into professional values: craftsmanship through technical competence, project success through team effectiveness, and vision realization through big-picture thinking (Rottmann et al., 2015).

One example of research that specifically outlined the difference between student perception of leadership in and out of an engineering context was written by Schell, Hughes, Tallman, Kwapisz, Sybesma, and Ranch (2019). They found that engineering students focused on different ideas, depending on whether leadership was defined in an engineering context or not. Participants in the research said inspiring a team or having a big picture vision was important when discussing leadership; however, those same

students highlighted technical expertise and problem solving when talking about engineering leadership.

Finally, there is one subfield of engineering education that diverges quite a bit from the approach towards values discussed thus far: the value of a liberal education (e.g., ASEE-LEES) in leadership development. This may be represented by Neeley's (2015) promotion of "principled nonconformance," or authenticity. In her argument, the truly responsible engineer is not only knowledgeable, but she is able to "…operate outside professional, cultural, and social paradigms" (p. 5). This is because such engineers have developed judgment guided by professional values: "to serve the ideals of their profession, to optimize the good that engineering brings to society as a whole, to serve the long-term welfare of their employers, and to achieve fulfillment as individuals" (p. 3). In summary, current scholarship in engineering leadership is clear that leadership is an important value of the engineering profession and that students require more knowledge about-- and appreciation of-- this aspect of engineering practice.

2.2.4.8. Technical Skills. Technical skills are essential to engineering identity, and the backbone of communal recognition of competence. However, pedagogies that develop technical skills, while essential to engineering identity, were not broadly addressed—for example, only 2/27 literature sources highlighted the importance of technical skills in leadership development (E. C. Johnson et al., 2015; Rottmann et al., 2015); and none of the SLR sources argued for further technical skill training to support leadership development. That said, practices such as group work (Wieman, 2006), feedback (A. Collins, Brown, & Newman, 1988), and authentic experiences (Johri, Olds,

& O'Connor, 2014) are recognized to also develop engineering expertise, as well as leadership competence. Nonetheless, the limited focus of technical skills in leadership development may be due to their assumed centrality in the profession, due to their centrality in existing engineering education programs, or due to industry's acceptance of the technical capabilities of engineering graduates. Regardless, it is noted that these skills are an important competency of engineering leadership (e.g., Racine, 2015).

2.2.4.9. Social Skills. Finally, social skills promote better interpersonal experiences, which lead to more accurate recognition, stronger belonging with a community, and more effective leadership behaviors. This was the most widely mentioned topic in the SLR literature. Social skills were addressed in four basic ways by the literature. First, researchers suggested that developing basic social skills was vital for leadership success. In addition, social skills facilitated interpersonal interactions, such as relationships, communication, and empathy (Klassen et al., 2017). And by definition, they are essential to a sociotechnical discipline. Second, researchers suggested didactic approaches to understanding leadership, by addressing the complex interpersonal skills needed to practice it well. Examples of approaches include leadership development programs (West, 2017), leadership workshops (Reeve et al., 2015), or broader liberal education (Neeley, 2015). The third way social skills were address were in terms of unique characteristics, through personality (Montoya et al., 2015; Nino, 2016) or leadership skills (Rosch et al., 2014) assessments. These were intended to provide students with insight into their particular social skill strengths and weaknesses. Finally, intrapersonal development was also addressed, as it is a core component of interpersonal

interactions. Specifically, Ulrich (2017) suggested providing professional engineering managers with tools for dealing with their own relatively underdeveloped emotions. In summary, social skills are critical to leadership. They are also very complex and require prolonged practice to develop effectively. The identity lens provides a context for dealing with the individual, complex, and nonlinear characteristics of social skills.

2.3. Focusing the Study

While there is need for full understanding of the impact of instructional strategies on leader identity, the scope of this research is more limited for several reasons. First, an ambition of this project was practical: to develop an effective short-term intervention that could be easily integrated into existing traditional classroom and program formats. Hence, the scope had to be limited enough to fit in 1-2 class sessions. In addition, the intervention needed to complement existing programmatic features, such as group work, classroom discussion, and extracurricular activities. Finally, to maximize the effectiveness of this limited intervention, the literature was reviewed to find those features that were most impactful for student leadership development.

Another reason for limiting the scope is that the gap in the literature is too broad to be filled with one study. Rather, the scope aimed to provide a well-grounded, compelling first step to fill this gap. And the scope had to conform with that more appropriate for a doctoral dissertation. Hence, the intent of this study is to provide insight into the influence of the most highly impactful instructional features on engineering leader identity. An important question that guided this process was the

following: “Which features do students need to develop as leaders but are not typically provided in the undergraduate curriculum?”

2.3.1. Core Features

Three criteria were used to guide the selection of core leader identity development features, based on the reasons for limiting the scope of the study. These core features were then used to inform the creation of an identity-informed intervention. First, the feature had to be highly important to engineering leader identity development. This criterion ensured that the intervention would focus on the most impactful contributors to identity growth. Second, the feature should not be widely used in traditional instruction. For example, technical skills (such as are required for effective problem solving) are the bread-and-butter of engineering education, so foregrounding them is not an effective use of resources. Third, the intervention length required to effect change should be short. This criterion ensures that the intervention could be easily integrated into existing program structures. This was useful not only for this existing research, but for subsequent integration of the intervention in engineering programs. For example, while extensive trainings in effective group social skill could be valuable in identity formation, they require long-term training to cultivate. Using these criteria, four leader identity development features emerged as core to an effective short-term intervention: reflection / feedback, peer / group learning, tools / language, and values. Table 1 summarizes the application of these criteria.

2.3.1.1. Reflection

Reflection is possibly the most vital component of identity growth. Its central role in self-authorship (the foundational identity development

process) foregrounds its importance in intrapersonal development. Reflection also enables the growth of belonging with a professional community, by imagining how one could work in a profession and by aligning one's values with those of the profession. Regarding engineering identity, recognition functions as a core pillar of the PCIR model (Godwin, 2016). Finally, reflection and feedback were widely cited in the engineering leadership literature as important classroom practices for cultivating identity (e.g., Klassen et al., 2016; Rottmann et al., 2018). Moreover, reflection exercises can be easily integrated into existing instructional practices. Of course, this approach can also be expanded to occupy an entire semester, where resources exist to explore one's experiences more fully (e.g., Nino, 2016). Finally, it is one of the least integrated

Table 1: Leader identity development features

Leader Identity Development Feature	Identity Importance	Use in tradl. Instruction	Intervention length	Core feature?
Reflection / Feedback	**High**	**Low**	**Short**	**Yes**
Authentic Experiences	High	Medium	Long	No
Scaffolding	Medium	Medium	Medium	No
Peer Learning / Group Work	**High**	**Medium**	**Short**	**Yes**
Differing Perspectives	Medium	Low	Short	No
Tools / Language	**High**	**Medium**	**Short**	**Yes**
Values	**High**	**Low**	**Short**	**Yes**
Technical Skills	Medium	Wide	Long	No
Social Skills	Medium	Low	Long	No

Bold indicates core features

features in technical education (Colbeck, Campbell, & Bjorklund, 2000; Harvey & Jenkins, 2014; Nino, 2016).

2.3.1.2. Peer Learning / Group Work. The second core feature is peer learning and group work. While this approach is regularly used, especially in upper-division courses, it was chosen because it provides such fertile context for meaningful experiences. This provides an environment for peer discussion of both new concepts and shared project responsibilities. It enables students to talk and hear about new ways of seeing themselves. This can lead to increased trust, understanding, and courage, especially regarding personal growth. Furthermore, it enables students to hear diverse perspectives and reflect more meaningfully. However, the environment can also be impotent or problematic, depending on guidance and scaffolding provided to the group (Rosch, 2015).

2.3.1.3. Tools / Language. The third is presenting and using the tools and language of engineering leadership. While the literature suggests that 'learning by doing' is essential for leadership development (Klassen et al., 2016), basic instruction is important for developing more complex understanding and for discussing various perspectives on leadership in an informed way. This is especially valuable when students are initially exposed to engineering leadership models (Komives et al., 2005). Fortunately, introducing students into basic relational models is relatively quick and simple.

2.3.1.4. Values. The fourth core feature is values. As noted previously, contextualizing leadership within the engineering profession is important to lowering resistance to the idea. Specifically, explaining leadership in terms of the values of engineering (e.g., technical competence and problem-solving) enables students to feel a sense of belonging more readily in terms of alignment and imagination. While various value frameworks are highlighted in leadership program mission statements (Klassen et al., 2016), they also must be clearly outlined in smaller-scale interventions to affect student perceptions of leadership. Finally, values can be easily integrated with, and naturally expressed through, tools / language, while the 'cost' of leveraging this feature is minimal.

2.3.2. Summary

Nine features of identity-based instruction have emerged in the literature of engineering leadership identity and adjoining fields. Of those, this research focuses on four core features due to their importance and practicality in short-term research in engineering leadership identity: reflection/feedback, peer learning/group work, tools/language, and values.

Group work (hereafter referencing both group work and peer learning) is widely used in current instructional environments, so its benefits can be easily leveraged. Reflection (hereafter referencing both reflection and feedback mechanisms) is central to identity formation in terms of self-authorship, professional identity, and leader identity growth. Hence it is not surprising to see it widely supported by the engineering leadership literature. While reflection-based approaches are rarely supported in

undergraduate engineering programs, they can be easily integrated into existing instructional structures (e.g., Nino, 2016). Language (hereafter referencing both tools and language) is essential to reflection, as it provides the tools necessary to consider and evaluate complex and well-defined structures through which students can think and talk critically. Language may also expose students to authentic practices—hence values—of the profession. Therefore, students can both think in an informed way and create meaning making structures, which can be powerful forces in continued professional identity development. In summary, the literature suggests that language and values are of vital importance to reflection that cultivates professional identity growth, so it is hard to imagine one of these three without the others. Group work, on the other hand, seems to be beneficial to the other three core features, without being essential.

In sum, these core features emerged by focusing on their importance to identity development, their presence in existing programs, and the ease of implementing them. Finally, it should be noted that reflection is the central feature, and it is vital to the effectiveness of the other three features. Therefore, instructional approaches that foreground these four core features and integrate an identity lens will be called *reflexive leadership instruction* for the remainder of this dissertation.

2.4. Assessing Engineering Leader Identity

With the growth in engineering leadership education and programs, measuring effectiveness of interventions and programs has grown in importance (Klassen et al., 2016). While empirical engineering leadership measures exist (e.g., Ahn et al., 2014; Guastello, 2011; Laguador, Velasquez, & Forendo, 2013), none were found to take an

identity-based approach. Rather, this research has echoed the concern that quantitative identity-based research of engineering leadership has used measures not specific to engineering (e.g., Dugan et al., 2013; Knight & Novoselich, 2017; Montoya et al., 2015; Rosch et al., 2014), which may be problematic given the supposed unique characteristics of engineers—such as introversion (Meyers et al., 2012), value for technical mastery (Tonso, 2006), and strong work ethic (Loui, 2005). To address this concern, Borrego, Patrick, Martins, and Kendall (2018) have proposed and validated a direct measure of engineering identity intersection with personal identity, which may hold promise in exploring professional identity intersectionality (Choe, Martins, Borrego, & Kendall, 2019).

The number of identity-based measures are growing in the leadership literature (Dinh et al., 2014), with many suggesting this approach is important for development (e.g., D. V. Day & Dragoni, 2015; Dugan, 2012; Ibarra et al., 2010). Even so, Epitropaki et al. (2017) "…generally observe an absence of well-established leader and follower identity measures that have been used consistently..." (p. 5). Nonetheless, in addition to providing extensive discussion of leadership measures outside the scope of this research, their discussion of self-report measures (pp. 34-35, 87) outlines several popular self-report and indirect measures. Selenta and Lord's (2005) Levels of Self-Concept Scale (LSCS) uses a 15-item multi-level (personal, relational, organizational) measure, but its validity has been challenged (Marnburg & Luo, 2014) and its focus is relational leadership only. Recently, the 14-item Identity Leadership Inventory was created using social identity theory (Steffens et al., 2014), but used a professional population to explore

leader identity. Of particular importance to this research, Hiller (2005) developed the Leader Identity Scale (LSI) based on self-schema approaches to identity. The self-schema approach measures three aspects of leader identity: how it describes oneself, how important it is to oneself, and how certain one is about it. This 12-item measure has been used to evaluate leadership development (David V. Day & Sin, 2011) as well as engineering leader identity (Rosch & Imoukhuede, 2016).

In addition to measuring the degree of leader identity, measures have also been developed to clarify beliefs about the nature of leadership, such as Wielkewicz's (2000) LABS III, Kouzes and Posner's (2005) LPI, and Carifio's (2010) RLQ. Chan and Drasgow's (2001) MTL has been used to explore engineering leader identity (Rosch, 2015) as it probes student motivation to pursue leadership according to three factors: affective-identity, social normative, and non-calculative. However, the MTL has demonstrated limited utility over Hiller's LSI in an engineering leadership context (Rosch & Imoukhuede, 2016). A second measure to explore beliefs about leadership is based on Drath's (2001) Orientation Toward Leadership (OTL). A 37-item measure was developed to explore students' and nursing professionals' belief in leadership along three non-orthogonal factors: leadership as process, as power over others, and as capability to learn (Hiller, 2005).

Two sources of national surveys important to the literature are the Higher Education Research Institute (HERI) at UCLA and the National Survey of Student Engagement (NSSE) at Indiana University. HERI administers two surveys which can be matched by students: the Freshman Survey (TFS) and the College Senior Survey (CSS).

These surveys measure a host of demographic and college-experience variables that have been used to explore college influences on engineering leadership development (Hughes et al., 2018b; Hughes, Schell, et al., 2019b). It has been used to explore aspects of engineering identity (Hughes, Schell, et al., 2019a) and leader identity (Hughes, Schell, Tallman, et al., 2019). The NSSE survey is a large national cross-sectional instrument that explores student experiences annually. While its primary focus is on student perception of their college experience and how it affected their engagement, additional modules may expand the scope. For example, a pilot model on leadership was tested in 2015. This dataset was used in the MSU literature stream to identify relationships between leadership experiences and leadership outcomes (Schell & Hughes, 2017b; Schell et al., 2018a, 2018b, 2018c).

In summary, engineering leadership measures are available, but limited measures exist to probe identity in a student population in terms of development. On the other hand, the leadership field has a growing body of leader identity measures that can represent the strength of one's leader identity as well as one's leadership beliefs, from a variety of frameworks. However, consensus has not yet settled behind one specific approach.

2.5. Summary

This literature review has taken a macro to micro strategy. It started with a broad review of four adjoining identity fields to establish frameworks for understanding identity within the context of engineering leadership. From there, a systematic literature review examined a scoping set that focused on engineering leadership identity. Finally, a final

literature set was analyzed, in terms of four broader identity theories. This analysis clarified nine features that support identity growth within an engineering leadership context: Reflection, Authentic Experiences, Scaffolding, Group Work, Differing Perspectives, Language, Values, Technical Skills, and Social Skills. In addition, four core features emerged as especially important for this research: Reflection, Group Work, Language, and Values. Finally, assessments of engineering leadership-related measures have been explored.

2.6. Research Questions

Findings from the literature review led to a defined research purpose. The literature gap indicated that little research has explored engineering leader identity development, with even less understood about how to effect that change. However, a systematic review of the literature, combined with identity lenses from adjoining fields, has outlined a group of instructional features that may be influential. An approach that operationalizes these features within an identity lens was defined as reflexive instruction. Hence, this research lessens the literature gap through the following purpose: examine the impact of reflexive leadership instruction on student leader identity.

To address this research purpose, five research questions were developed, corresponding with six hypotheses (Table 2). A conceptual map of the causal and correlational relationships being explored through these research questions and hypotheses is illustrated in Figure 16. Research Question 1 (RQ1: Does reflexive leadership instruction about engineering leadership influence leader identity?) explores leader identity, due to reflexive leadership instruction. However, RQ1 does not address

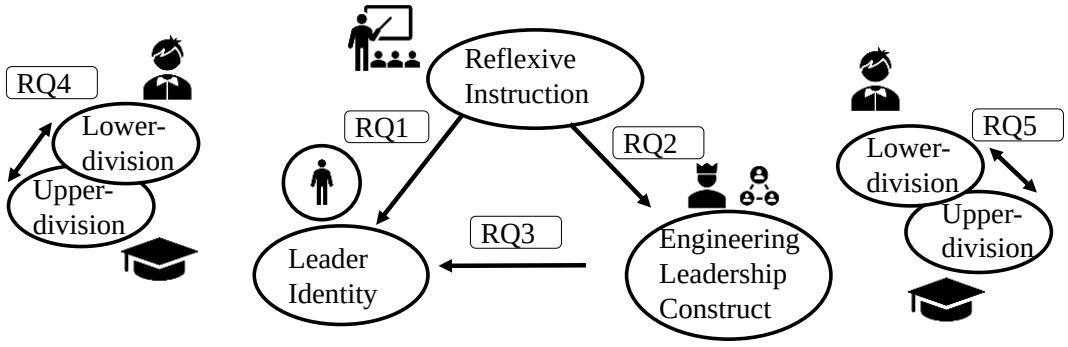

Figure 16. Research questions map.

what one *means* by leadership: Research Question 2 (RQ2: Does reflexive instruction about engineering leadership influence engineering leadership construct?) addresses change in leadership construct due to reflexive leadership instruction. Leadership construct reflects how an individual defines engineering leadership and is essential to understanding leader identity (Dugan, 2012).

The next research question (RQ3) addresses the relationship between leader identity and leadership construct: Does engineering leadership construct influence leader identity? The relationship between leader identity and construct is of interest due to the indication that how engineers might perceive leadership (e.g., dynamic, charismatic personality) may have a strong influence on leader self-identity (LSI) (H3x). Change in these concepts is of particular interest (H4x), as this would demonstrate the influence of the intervention, and it would provide some evidence of a causal relationship between construct and identity. These first four hypotheses were separately proposed for lower-division and upper-division student populations, leading to different hypothesis questions for the respective research questions. The L and U designations (Lower- and Upper-

division, respectively) are for convenience and are not intended to definitively describe the class level of individual participants.

The last two Research Questions address the varying impact of the intervention on lower-division versus upper-division students. These are intended to measure the potential differences between lower- and upper-division students. In other words, what difference does three years (give or take) tend to make? Research Question 4 (RQ4: Does reflexive instruction about engineering leadership influence lower-division students' leadership identity differently than it influences upper-division students' identity?) addresses differences in leader identity change. Similarly, Research Question 5 (RQ5: Does reflexive instruction about engineering leadership influence lower- division students' engineering leadership construct differently than it influences upper-division students' construct?) addresses differences in construct change, based on class level. In other words, the intervention may have influenced lower-division student construct development in different ways than it influenced upper-division students.

These research questions were included to address student development. The student development literature, as well as the simple structure of the engineering curriculum, indicate that there are substantive differences between these groups of students. For example, students tend to report a greater sense of competence, in both intellectual and interpersonal domains, as they progress through college (Astin, 1993). They also tend to develop stronger self-authorship through difficult challenges, encountering diverse perspectives, and taking responsibility for complex tasks (Baxter Magolda, 1998). In fact, one characteristic of identity is that it is dynamic; people change

and grow throughout their lives. College is a particularly impactful experience for identity development, across almost all domains. Quantitatively comparing lower-division and upper-division responses would provide insight into the ways their engineering leadership development may differ. This would have both theoretical and practical implications for developing engineering leadership amongst students.

2.7. Study Significance

This study addresses three important gaps in the existing engineering leadership identity literature. First, the existing engineering leadership identity literature indicates that identity-based approaches hold promise for cultivating leadership amongst undergraduate engineering students. While the literature in this field is growing, there is relatively little empirical evidence showing how this approach might work. By combining the existing engineering leadership identity literature with the literature of adjoining identity fields, this literature review has outlined four core features of an instructional approach that cultivates identity. By measuring the impact of such an approach on leader identity and engineering leadership construct, a first step would be taken in providing a practical model that supports leader development for engineering students.

Second, the existing literature is mixed on the varied ways year in school may impact leader identity and engineering leadership construct. Evaluating the difference between lower-division and upper-division students would provide insight into aspects of their development important to leadership. Moreover, understanding differences by year

in school would be valuable for engineering leadership programs, enabling them to further customize their programs to accommodate their students' need.

Third, the existing literature suggests that there may be a relationship between how engineering students think of engineering leadership and how they see themselves as leaders. This connection is important, as it may hold the key to eliminating barriers to leader identity, which is an important early step in leadership development. It may also provide insight into developing more complex ways of practicing leadership for existing leaders. Finally, this connection may provide insight into how to leverage existing skill-based programs to best cultivate engineering leadership. However, the relationship between leader identity and engineering leadership construct has not yet been quantitatively established. By measuring the relationship between these two components of engineering leadership identity, this study will further our theoretical understanding of important influences on leader identity for engineering students.

Table 2: Research questions and hypotheses.

Reference	Question	Null Hypotheses
RQ1	Does reflexive instruction about engineering leadership influence engineering leader identity?	H1L/U: Reflexive instruction about engineering leadership does not influence engineering leader identity of lower-/upper-division students.
RQ2	Does reflexive instruction about engineering leadership influence engineering leadership construct?	H1L/U: Reflexive instruction about engineering leadership does not influence engineering leadership construct of lower-/upper-division students.
RQ3	Does engineering leadership construct influence engineering leader identity?	H3L/U: Engineering leadership construct does not influence engineering leader identity of lower-/upper-division students. H4L/U: Change in engineering leadership construct does not correlate with change in engineering leader identity of lower-/upper-division students.
RQ4	Does reflexive instruction about engineering leadership influence lower-division students' leader identity differently than it influences upper-division students' identity?	H5: Reflexive instruction about engineering leadership does not influence lower-division students' engineering leader identity differently than it influences upper-division students' identity.
RQ5	Does reflexive instruction about engineering leadership influence lower-division students' engineering leadership construct differently than it influences upper-division students' construct?	H6: Reflexive instruction about engineering leadership does not influence lower-division students' engineering leadership construct differently than it influences upper-division students' construct.

CHAPTER THREE

METHODS

Now that the literature has been explored and a gap in the research has been outlined, this chapter addresses the methodology used to pursue the research purpose: examine the impact of reflexive instruction about engineering leadership on engineering leader identity. This chapter will begin with a study overview, followed by sections on the intervention and measure development. Next, results and impact of the pilot study will be presented. Finally, the chapter will outline study design details, data collection, and analysis procedures.

3.1. Study Overview

This study explored the impact of reflexive leadership instruction on leader identity and engineering leadership construct amongst undergraduate engineering students. Survey research was used to quantitatively measure leader identity and engineering leadership construct as a function of reflexive leadership instruction, which was operationalized as a four-pronged short-term classroom intervention. The intervention consisted of classroom instruction, reflective assignments, and discussion (and related activities). The effects of two different interventions were measured: one for upper-division engineering students and one for lower-division students. The lower-division intervention was administered in three courses at two public universities; the upper-division intervention was administered in three courses at one public university.

The impacts of the intervention were measured through a pre-survey and retrospective post-survey of student self-reported measures. A pilot study was conducted and used to inform the present study design. Additional qualitative data was collected to support trustworthy interpretation of the results. Figure 17 provides an overview of the study that applies to lower- and upper-division interventions.

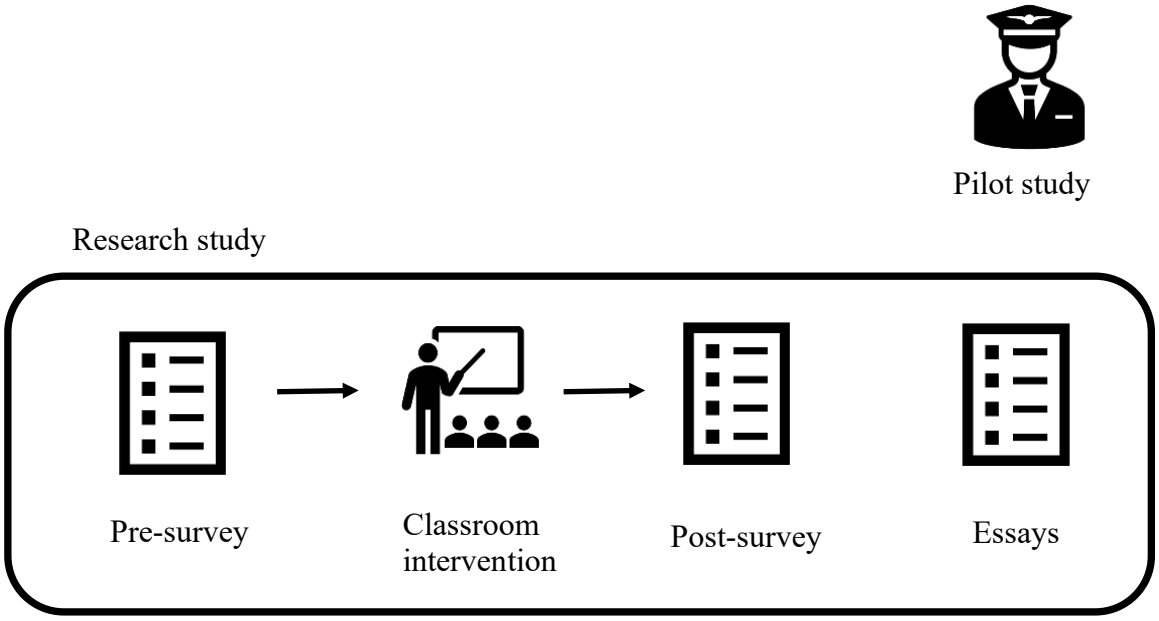

Figure 17. Study design overview.

3.2. Refined Intervention

The intervention for lower- and upper-division participants consisted of four components, bookended by a pre-survey and a post-survey, as illustrated by Figure 18: outlook essay, pre-lecture videos, classroom discussion, and reflection essay. The intervention design and activity details are addressed in the remainder of this section. A

pilot study was performed Spring 2020 (Tallman et al., 2020), with those results informing the current study design (Hughes, Schell, Tallman, & Kwapisz, 2020).

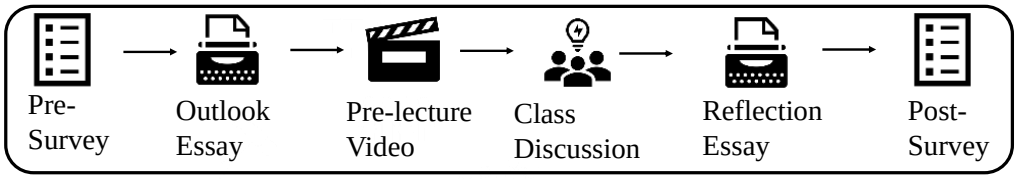

Figure 18: Intervention components.

3.2.1. Design

To create the intervention activities, several factors were considered. Most importantly, each activity was informed by the four core instructional features from the literature (reflection, group work, language, and values). These features describe important aspects of the classroom experience in cultivating leader identity growth, as outlined from the exploration of the literature. Key identity developmental processes from adjoining fields were also considered: self-authorship, belonging, performance /competence/ interest/ recognition, and differentiation. These instructional features and developmental processes were operationalized to teach students about engineering leadership. Where possible, other identity-based features were integrated, as well (such as social skills). Finally, pragmatic concerns were considered, such as class size and presentation limitations. The combination of these considerations formed the foundation for the development of an identity-based intervention.

By considering these factors, activities were iteratively proposed and revised, until a group of activities were identified that were supported by the literature review

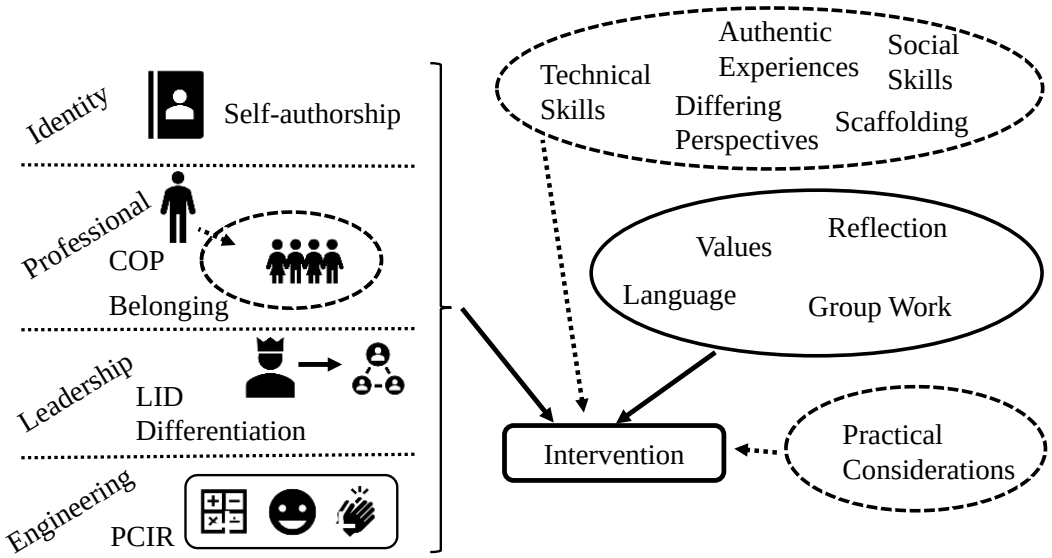

Figure 19: Intervention foundations.

findings; these activities leveraged the four key developmental processes and the four core instructional practices of identity (Figure 19). Four activities emerged: outlook essay, pre-lecture videos, discussion, and reflective essay. The outlook essay provided a benchmark for leadership beliefs and enabled later reflection. This essay was important to document participant engineering leadership beliefs going into the intervention, both for the researcher (to provide a rich data source for interpreting quantitative findings) and the student (to reflect on previous beliefs). The pre-lecture videos presented introduced various aspects of engineering leadership. The discussion activity provided opportunity for group discussion, class-wide sharing, and instructor feedback and scaffolding. The reflective essay facilitated personal reflection on engineering leadership. Finally, while each course instructor awarded participation in the intervention and research surveys slightly differently, the general approach was to award bonus credit for those who

participated in the surveys, thereby avoiding penalty for non-participants. Participation in the intervention (as opposed to the surveys) was expected, and assessments were completion-based. Each activity is described in more detail below.

3.2.2. Lower-division

While the overall structure of the approach was the same for lower-division and upper-division, specific activities differed so that they could be tailored to students' differing developmental stages. Because of differences between the intervention for lower-division and upper-division students, they will be described separately: the lower-division section includes most common aspects of the research, while the upper-division section details components unique to that participant group.

3.2.2.1. Outlook Essay.

The first core activity (following the pre-survey) was a 1-page outlook essay, asking the participants to define leadership and reflect on their own perspective of being "an emerging engineering leader" (Appendix J). The activity had several purposes. First, it established a baseline for leadership beliefs that was revisited during the second essay. Second, it primed students to think about engineering leadership, which is important to both the Community of Practice (CoP) mode of imagination and alignment belonging (Lave & Wenger, 1991), as well as imagining one's own provisional self, per Ibarra (1999). Third, it served as a source of qualitative data on student perspectives, which supplemented further interpretation and discussion of quantitative results.

3.2.2.2. Pre-lecture Videos. The second core activity consisted of three pre-lecture videos on leadership, assigned after completion of the outlook essay. The first video outlined three types of positional leadership, thereby illustrating a diversity of practices, while also introducing students to basic leadership terms. It introduced autocratic, democratic, and laissez faire positional approaches ("Leadership Styles," 2020). Next, students viewed an instructional video that outlined positional and relational leadership, addressing beliefs common during the LID differentiation stage (Komives et al., 2005). Finally, all students viewed a video that describes three orientations of engineering leadership: technical mastery, organizational innovation, and collaborative optimization (Rottmann et al., 2015). This provided scaffolding of what leadership looks like in the profession, which can be valuable for cultivating CoP alignment belonging (through consideration of values), and for envisioning relational leader identity. It also provided a context for students to talk more clearly about engineering leadership, giving them a chance to see it in a more heterogeneous and personal way (they will later write about which style they might pursue).

The first video has been used in previous classes at one of the universities. The subsequent two videos were created for this research by the researcher. These videos used a Khan-style video (KSV) approach (Khan, 2012) that followed practices recommended by Cognitive Theory of Multimedia Learning (CTML) (R. E. Mayer, 2002; Sweller, Ayres, & Kalyuga, 2011). Operationalizing these assumptions involved using a number of CTML good practices, such as narration and pictures together, using a conversational style, and moving from components to system (Richard E. Mayer, 2005).

Finally, the length of the video was less than 10 minutes, following research recommendations (e.g. Ibrahim, Callaway, & Bell, 2014; Johnstone & Percival, 1976). A full transcript of these videos is provided in Appendix AE., or they may be viewed on Youtube (https://www.youtube.com/playlist?list=PLhuDcb-jT0z9OuStmRVmanpuWjIZ904Vo).

3.2.2.3. Discussion. The third core activity was in-class discussion. For lower-division students, a single intervention class session focused on the prompt: "What type of engineering leader do you envision yourself becoming? Why?" Appendix K includes the full lesson plan for lower-division students. A three-step interview was conducted, in groups of four students. A three-step interview involves two students interviewing one another about the prompt (steps one and two). The third step requires one of those two students to summarize the other's perspective, to a second pair of students. This third step was followed for all four participants in the two pairs (per best practices in Barkley, Cross, & Major, 2014, pp. 121-125). This experience leveraged the benefits of reflection (Rosch & Imoukhuede, 2016), group work (Racine, 2015) and experiencing differing perspectives (Rottmann et al., 2018). Next, groups were invited to share some of their interview results, allowing the instructor to scaffold more complex ways of thinking about engineering leadership (e.g., re-phrasing student anecdotes and experiences using precise leadership language), to use the language of leadership, to provide feedback on group discussion, and to contextualize the value of leadership in engineering. Here, it is instructive to note that scaffolding of leadership styles was not done in a hierarchal manner (i.e., relational is better than autocratic), but in a conditional manner (i.e.,

different leadership styles are more or less effective under different conditions). This enabled students to think more critically about the characteristics and appropriateness of leadership styles. The class concluded with a brief discussion of practical steps for students interested in pursuing engineering leadership further, such as connecting with a faculty mentor (e.g., Komives et al., 2005; Stephens & Rosch, 2015) or investing in an interesting classroom or co-curricular group project (Knight & Novoselich, 2017).

3.2.2.4. Reflective Essay. The fourth core activity was a 1–2-page reflection essay, assigned after the final in-class discussion (Appendix K). For lower-division students, the essay was due soon after the single class. This essay included two prompts: "How has your perspective on engineering leadership changed / strengthened / weakened since your outlook essay?" and "Which—if any— practical steps [to develop as engineering leadership] sound personally interesting?" This activity had three purposes:

1. It provided a reflection opportunity for students to consider how their own ideas had changed to leverage Kegan's (1982) subject-object interviewing benefits.
2. It provided qualitative insight into how the intervention had affected the students.
3. It allowed students to reflect on practical steps to pursue leadership development (e.g., extra-curricular experience, mentorship, curricular engagement), thereby facilitating all three belonging modes of the CoP (Lave & Wenger, 1991).

3.2.3. Upper-division

The intervention used for the upper-division students followed a similar structure as that for the lower-division participants. However, slight modifications were made in each aspect of the intervention, as noted previously. This section outlines specific ways in which the upper-division participant experience differed from the lower-division; in all other ways not mentioned in this section, the interventions were identical for the two groups. The outlook essay was identical for both groups.

3.2.3.1. Pre-lecture videos. Upper-division students were not shown the first video (on various types of positional leadership). This video was omitted in the interest of intervention brevity and the expectation that it would have minimal impact. This expectation was because upper-division students typically have adequate experience in various groups to understand these differences already. In addition, it was expected that many of the students had already seen the video, as it was a component of a required introductory course in an earlier year.

3.2.3.2. Discussion. For the upper-division intervention, the third activity involved two class sessions, with an interim individual assignment. The first in-class activity focused on practical steps a student might take to develop as an engineering leader, using a group round robin (see Appendices L and M for full lesson plans for each phase of this activity). A group round robin involves each person (in a 4-5 member group) suggesting one practical step for leadership development, in turn (Barkley et al., 2014, pp. 108-111). This approach introduces multiple perspectives and highlights the

value of each member by focusing equal attention on everyone. Moreover, talking about practical steps frames leadership in an active, authentic context. A class-wide discussion of group responses was guided by the instructor. Like the lower-division discussion, it concluded with a summary of the practical steps discussed.

For upper-division participants, an additional assignment focused on practical steps that individuals could take towards leadership growth during the coming semester. This additional step leveraged reflective practice (e.g., considering and pursuing one's own leadership goals). To provide a framework for these practical steps, students were given a 5–10-minute overview of SMART goals (Doran, 1981; Drucker, 1976). The lesson plans may be found in Appendices L and M. At the next class session, the instructor led a class-wide discussion about participants' SMART goals, for approximately 15 minutes. This discussion explored various practical goals and types of engineering leaders. In addition, the instructor answered questions and normalized self-directed development.

3.2.3.3. Reflective Essay. For upper-division participants, the reflection essay also included reflection on the impact of practical steps taken and SMART goal achievement (Appendix M). The essay was due late in the semester (the due date and assignment were provided at the conclusion of the intervention), to give students time to pursue SMART goal practical steps.

3.3. Methods of Measurement

The survey design followed a pre-survey post-survey format, where surveys are administered before and after an intervention. Pre-survey and post-survey included identical items that explored leader identity and leadership construct. These items were sourced from three published surveys: Hiller's (2005) LSI and OTL measures, and an identity overlap measure (Borrego et al., 2018). In addition, the surveys included several control questions (e.g., gender) and measures of other outcomes (e.g., leadership interest) that were meant to provide further insight into participant perspectives on identity. The pre-survey included demographic questions and identifying data, which allowed pairing the post-survey and pre-surveys. Lower-division and upper-division participants were given the same surveys.

To measure change from the intervention, a retrospective post-survey was used. This survey design approach asks participants "to simultaneously assess their capacity at the beginning of the [intervention] and… at the end of the [intervention]" (Rosch & Imoukhuede, 2016, p. 3611). These assessments are designated as BEFORE and NOW, respectively. The survey structure asked about a participant NOW belief of a particular leadership characteristic, followed by the corresponding question retrospectively (BEFORE). This format follows Rosch's (2016) use of retrospective surveys exploring engineering leader identity. This format is shown to measure intervention impact more effectively than traditional pre-post formats, especially in the context of leadership development (Dugan et al., 2011): it mitigates issues with response-shift bias, or the phenomenon where a person's standard for measurement changes over the course of

time. Response-shift bias may be due to participants getting better at filling out surveys, the test-retest effect, or other time- or experience-based effect not directly tied to the intervention. Therefore, subjective measures may be "…confounded by this distortion of the internalized scale yielding an invalid interpretation…" (Rohs, 1999, p. 28 1845). In fact, Rohs (1999) empirically tested and demonstrated the detrimental impact of this bias on reported leadership growth of college agriculture students, using a quasi-experimental design with random assignment to intervention (both pre-post and then-post) and control groups. Within the engineering leadership identity literature, Rosch (2016) used this approach to explore leader identity (Hiller, 2005) and Motivation to Lead (Chan & Drasgow, 2001). His review of this approach provides additional justification for its use (Rosch & Imoukhuede, 2016, p. 3615). The pre-survey measure was given to address exploratory questions about the beliefs of lower-division and upper-division students before focused leadership instruction.

There is also concern that participants may artificially inflate their perceived growth due to the intervention in a retrospective survey, due to a desire to conform to social or researcher expectations (Miles & Huberman, 1994). To address this concern, the researcher emphasized that the main purpose of the research was to understand student perspective, not elicit a certain response or 'right answer'. This was also done to mitigate changes in participant behavior and perception simply due to knowing that they were in an experiment, sometimes called the Hawthorne effect. Similarly, to limit potential experimenter bias towards a particular leadership model (especially towards

relational leadership) the researcher gave positive and appropriate examples of each leadership model presented.

A 7-item Likert-type scale was used for core and control variable items, the same as the options available in the validated measures (Krosnick & Presser, 2010). In addition, the literature suggests that a 7-item approach is preferred when paired *t*-tests are used for analysis (Lewis, 1993), and when small response distinctions are important to capture and can be expressed (Finstad, 2010). This approach allows one to treat levels of an ordinal variable as continuous. Finally, it should be noted that while 7-item levels may have higher validity, traditional Likert 5-level items may result in greater observed effect sizes than higher-level items (Todman & Dugard, 2001, pp. 214-215). A summary of the study variables may be found in Table 3. Permissions were obtained to use all previously published measures and items, where required. Pre-survey items 29-32 and post-survey items 47-50 used with permission from The College Student Report, National Survey of Student Engagement, Copyright 2001-19 The Trustees of Indiana University. A full list of the variables measured may be found in Appendix I. Appendices N and O include the final pre-survey and post-survey, respectively.

Table 3: Variable summary.

Demographics	Core Variables	Control Variables	Other Outcomes
Name	Leader identity (LSI)	Leadership position	Engineering identity
Major	Leadership Construct (OTL & ELR)	Alignment with Engr	Interest
Class		Integration in class	Self-efficacy
Gender		Interaction with diverse	
Race /ethnicity			

3.3.1. Core Variables.

Two core variables that directly address the research questions are leader identity and engineering leadership construct. A wide array of leadership assessments was evaluated using criteria defined by a combination of the research agenda and existing literature. The four criteria included the following: first, the measure must assess leader identity; second, it must address development; third, it must use self-report measures; and fourth, it must address frameworks relevant to engineering leadership. Two measures emerged that met these criteria: The Leadership Self-Identity (LSI) and the Orientation Toward Leadership (OTL) tests. In addition, a fourth factor of leadership construct assessed the relationship between engineering and leadership (Borrego et al., 2018). These previously validated measures consisted of a total of 19 items. Justification to select the leadership measures was based on the four criteria grounded in the leader identity literature (e.g., David V. Day & Sin, 2011; Dinh et al., 2014; Epitropaki et al., 2017; Van Knippenberg et al., 2005), per Table 4.

3.3.1.1. Leader Identity. Leader identity assesses the level to which an individual sees themselves as a leader. It was measured in this study by seven items, following Hiller's (2005) widely used Leadership Self-Identity (LSI) test (e.g., David V. Day & Sin, 2011; Epitropaki et al., 2017; Rosch & Imoukhuede, 2016). The test probed the descriptiveness ("does this statement describe you"; 4 items) and importance ("is this statement important to you"; 3 items) of a particular identity through self-reported, Likert-type scales. The seven items reflected the "core leadership self-identity factor" (Hiller, 2005, pp. 36-37), with one item removed due to low (less than 0.6) factor loading

(Rossi, Wright, & Anderson, 2013; J. P. Stevens, 2012). The measure included items such as "I am a leader" and "Others see me as a leader."

3.3.1.2. Engineering Leadership Construct. Engineering leadership construct assesses how an individual understands engineering leadership, in terms of four factors. Three factors are based on Orientation to Leadership (Drath, 2001) and subsequently refined by Hiller (2005): power, development, and process. Power, or Dominance, (3 items) "consider[s] leadership from a personal dominance perspective, view[ing] leadership as something that people possess as a result of their position or individual traits (or both)" (Hiller, 2005, p. 17). An example of an item measuring this factor is, "Leaders order other people around." Development (4 items) reflects the belief that leadership can be developed (e.g., "Skills and abilities for leadership can be developed"). Process, or Shared, (4 items) reflects a leadership that is shared within a group to make decisions (e.g., "Leadership is the responsibility of everyone in a group") (Drath, 2001; Hiller, 2005). Hiller's (2005) refined 16 item measure was further pared down for this research by eliminating measures that loaded poorly onto their respective factors (Rossi et al., 2013). This resulted in 11 items measuring the three OTL factors in the leadership construct.

While the three factors of the OTL were not explicitly designed for use with the LID model, they probe essential components of the differentiation process and precursors to it. For example, "One's formal position determines whether they are a leader" (pre-

Table 4: Leadership measure selection.

Source	Scale name	Focus	Exclusion Reason
Hiller (2005)	LSI	Ldrshp self-schema	N/A
Drath (2001); Hiller (2005)	OTL	Power, development, process	N/A
Ahn	4-factor E L	Expert engr ldr traits	Validity concerns
Wielkewicz (2000)	LABS III	Hierarchal / systemic	Misaligned with engr ldr approach.
Kouzes & Posner (2005)	LPI	5 practices of ldrshp	Indirect, value-based (not identity)
Carifio (2010)	RLQ	Relational ldrship	Meant for practicing leaders
Chan & Drasgow (2001)	MTL	Affect, norm, non-calc	Less relevant in engr ldr context
Borrego (2018)	Engr Identity	Identity overlap	N/A
Selenta & Lord (2005)	LSCS	Multi-level	Only focuses on relational leadership, indirect, validity concerns
Steffens (2014)	ILI	Social identity	Only for professional population

survey item 14) directly assesses one's belief in a positional view of leadership. This belief is central to a changing view of leadership in the transition from Stages 3 to 4 of the LID model: "Holding position does not mean I am a leader" (Komives et al., 2009, p. 18). The process factor (e.g., "Leadership happens when people collaborate" [pre-survey item 7]) highlights a view of leadership as a group-based process. This is the essential perspective that characterizes the immersion step of Stage 4 (Leadership Differentiated) of the LID model: "Awareness that leadership is a group process" (Komives et al., 2009, p. 19). In summary, OTL factors assess leadership beliefs that are important to leader identity development amongst college students, according to the LID model.

The fourth factor of engineering leadership construct is how participants view the relationship between engineering and leadership (ELR). This item assesses an

individual's perception of how engineering and leadership identities overlap. This one-item measure was modified from Borrego, Patrick, Martins, and Kendall's (2018) measure of engineering identity. The question in this research probed belief in the overlap of leadership and engineering identity, rather than the original probe of leadership and personal identity; however, the structure of both questions probed the intersection of different aspects of identity. This variable is important because the literature suggests that the perceived value of leadership to the profession substantively affects how engineering students (and engineers) value leadership, thereby influencing their willingness to cultivate a leader identity. Faulkner (2007) includes a critical discussion of the relationship between student value of leadership and their perception of it professionally; later research (Rottmann et al., 2015) provides a qualitative analysis of the relationship. Hence, four items addressed the shared factor, four items addressed the development factor, three items addressed the power factor, and one item addressed the relationship between engineering and leadership.

3.3.1.3. Research Questions. The five Research Questions related to the survey variables are illustrated in Figure 20. The leader identity measure provides the dependent variable relevant to RQ1, RQ3, and RQ4. Seven items combine to form two factors of leader identity: descriptiveness and importance. The leadership construct measure provides the dependent variable for RQ2 and RQ5, as well as the independent variable for RQ3. 12 items combine to form four factors of leadership construct: leadership as shared, leadership as development, leadership as power, and leadership relationship with

engineering. Student class level separates sample populations, which are compared in RQ4 and RQ5 and separate hypotheses for RQ1, RQ2, and RQ3.

3.3.2. Other Outcome Variables.

Three additional outcome variables were also explored: interest, self-efficacy, and engineering identity. These variables, along with the control variables, were measured by new instruments developed for this research using items based on existing identity theory. While they were not directly used to test any hypotheses, these variables are

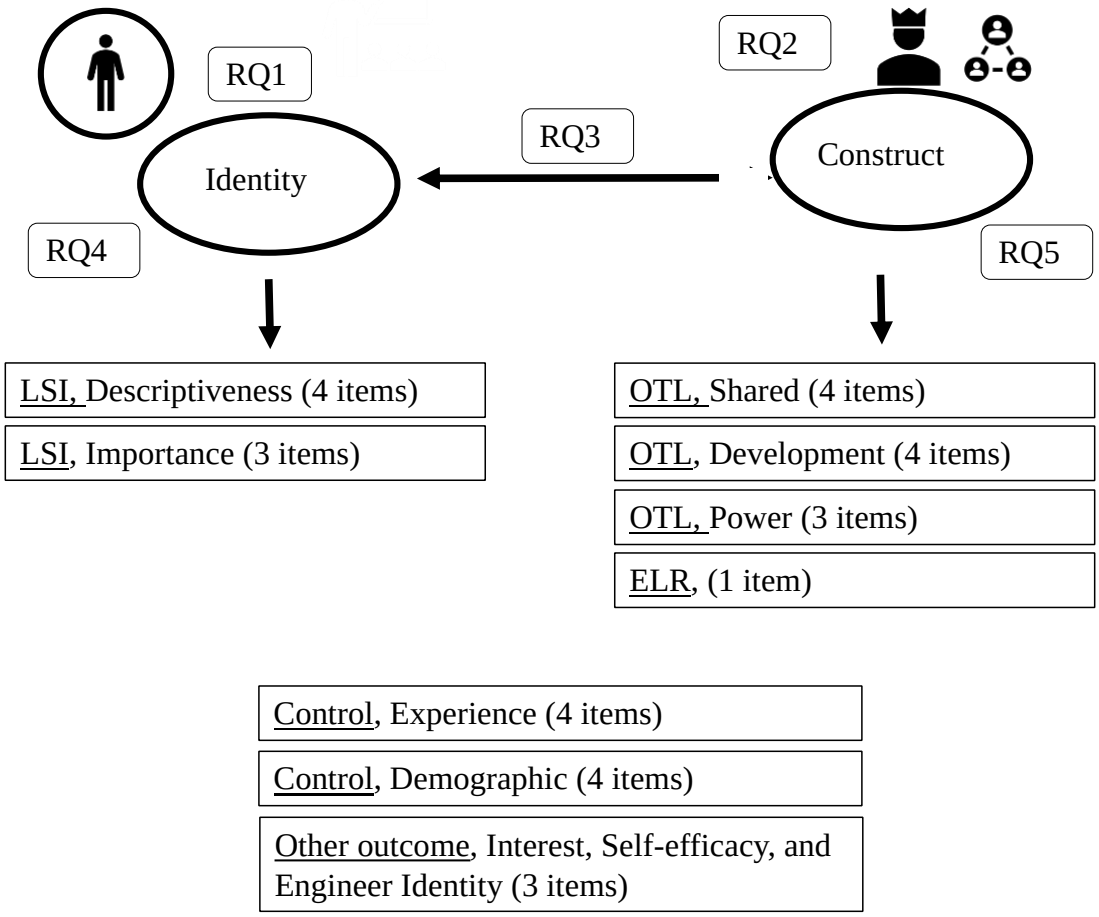

Figure 20. Measured variables.

shown to correlate with student identity (e.g., Bandura, 1986; Eccles et al., 1983; Lent, Brown, & Hackett, 1994). Hence, each of these variables may reflect important aspects of student engagement with engineering leadership.

3.3.2.1. Interest. Interest measures a participant's interest in developing leadership and is important to developing an engineering leadership identity. This variable was measured through one item that was used in the pilot study, derived from Godwin's engineering identity measure, which was based on the 2011 SaGE survey (Godwin, 2016; Godwin et al., 2016).

3.3.2.2. Leader Self-efficacy. Self-efficacy measures a participant's belief in their power to accomplish a task (Bandura, 1986). It is a core aspect of professional identity (Chickering & Reisser, 1993) and engineering identity (an outcome of recognition) (Hazari et al., 2010). This variable was measured through one item (based on LID model differentiation): "I can be a leader." A similar item was used in the pilot, where participants reported a significant increase (using a traditional pre-post measure).

3.3.2.3. Engineering Identity. Engineering identity measures the degree to which one considers oneself an engineer. The connection between engineering and leader identity is not well-established, but possibly important (e.g., Rottmann et al., 2015; Schell et al., 2018a). This variable was measured through modification of one (descriptive) item from the LSI: "I am an engineer." While measuring a complex construct like engineering identity generally requires multiple items, a single item was chosen for two reasons. First, the intent of this question was simply to identify strength of professional identity,

instead of particular ways in which one might identify with the engineering profession. Second, engineering identity is not used to address directly any research questions, rather it is included to provide additional context for engineering leader identity development. Finally, using qualitative data provided a safeguard from gross misinterpretation of this item.

3.3.3. Control Variables.

Four control variables addressed experiences that the literature suggests impact leadership development: previous leadership position, leadership alignment with program, integration of leadership experience in coursework, and interaction with diverse others. These four control variables were measured through corresponding items in the National Survey of Student Engagement (NSSE) at Indiana University survey (using a 4-level Likert-type scale), which have demonstrated impact on identity-related outcomes (e.g., Schell et al., 2018c). Position measures a participant's experience holding a leadership position through yes/no response. Leadership alignment with program measured the amount of alignment that existed between a participant's leadership role and a participant's academic program. Integration of leadership experiences measured the frequency with which participants had used aspects of their leadership role experience in academic courses. Finally, interaction with diverse others measured the frequency with which participants had interacted with people from a different background.

3.3.4. Demographic Variables.

Four demographic variables were included in the survey: class level, gender, race, and major. Class level was used to understand the makeup of participant groups, as development through college has been shown to be a highly influential factor in identity (e.g., Astin, 1993; Barber et al., 2013; Komives et al., 1998). Gender and race are widely regarded as a highly influential characteristic in engineering identity (e.g., Carlone & Johnson, 2007; Faulkner, 2000; Fleming et al., 2013; Tonso, 2006). The impact of major is not fully understood, but may be influential in leadership development (e.g., Handley, Plumblee, & Eerdman, 2018). Finally, names were used to track student response from pre-survey to post-survey, to validate any tracking through electronic administration of the survey, and to connect qualitative and quantitative data.

3.3.5. Data Collection Formats.

The data collection for this research consisted of two main categories of measures. First, quantitative data was collected via the pre-survey and retrospective post-survey. Second, qualitative data was collected through student assignments that were part of the intervention. This qualitative data also provided support of interpretation of the quantitative results, providing some of the same advantages as a multistrand sequential mixed methods approach, per Figure 21. Finally, it should be noted that each survey contained an identification item and an attention question to check for participant attention (i.e., Please choose response 2).

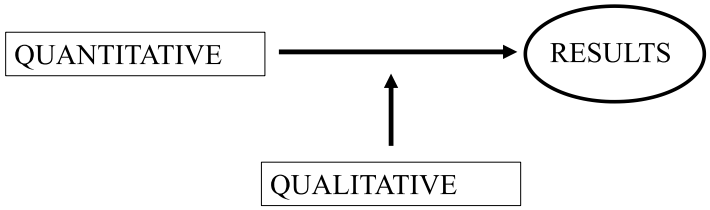

Figure 21. Qualitative methods use. Qualitative methods are used to inform quantitative findings (J. Creswell, Clark, Gutmann, & Hanson, df2010, p. 214).

3.3.5.1. Pre-survey. The pre-survey measured a total of 31 items: core (19 items), other outcome (3 items), control (4 items), and demographic (5 items) variables. In addition, one attention item (i.e., "This is a control question. Please choose response 2.") was included, for a total of 32 items. It was administered via Qualtrics electronically outside of class (Qualtrics, Provo, UT).

3.3.5.2. Post-survey. The post-survey measured a total of 48 items: core (38 items), other outcomes (6 items), and control (4 items) variables. The post-survey was two-staged (retrospective or BEFORE-NOW). The first stage (NOW) asked about student leadership at the present time. The second stage (BEFORE) asked about student perception of leadership at the beginning of the course. The survey structure asked about a participant NOW belief of a particular leadership characteristic, followed by the corresponding question retrospectively (BEFORE), resulting in two items probing the same variable. Demographics were not required, as the administration of the test via Qualtrics enabled pairing post-survey and pre-surveys. It was completed out of class.

3.3.5.3. Essay Responses. The Outlook Essay, SMART goal, and Reflection Essay assignments provided qualitative data. The primary purpose of collecting this data

was to additionally inform discussion of results and practice recommendations, when applicable. In addition, this data functioned as an additional resource to explore aspects of student identity and practice that may not be captured by the quantitative surveys.

3.4. Pilot Study

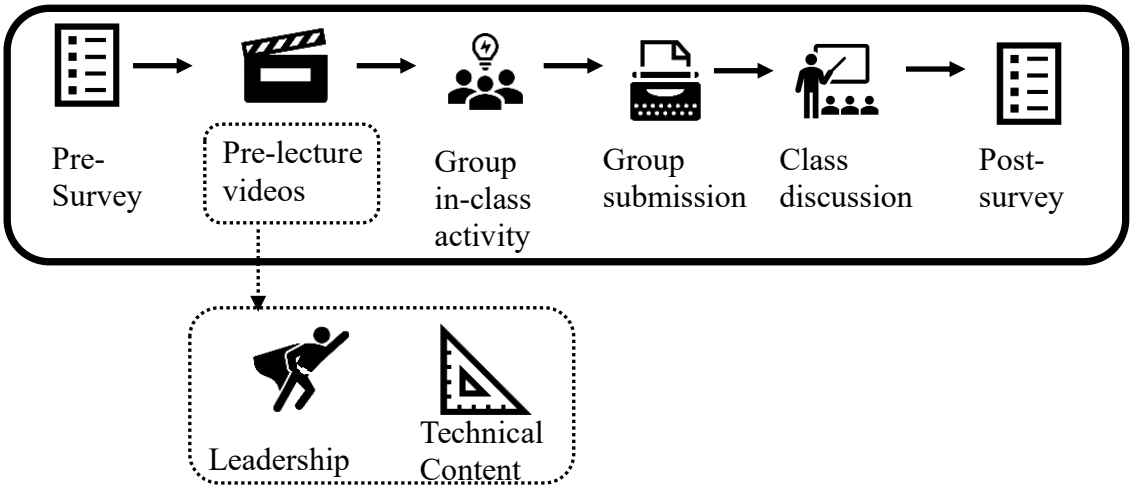

Figure 22. Pilot study format.

The intervention format, measures and expected impact were informed by a pilot study, Figure 22. The pilot involved a pre-survey, pre-lecture technical and leadership videos, a group project, class discussion of project and leadership experiences, and a post-survey (Hughes et al., 2020; Tallman et al., 2020). The format was online, due to institutional response to a global pandemic. The pilot study was performed at a Rocky Mountain land-grant university, over the course of one week in an introductory engineering course. Participants included 20 engineering students (out of a total of 41 students in the course) from two sections of the course.

The pilot intervention consisted of three prongs. The first prong included basic instruction on various styles of leadership and on technical aspects of cleanroom design. This instruction was provided via pre-lecture videos, recorded by the researcher. The second prong was a "jigsaw" activity, where each member of existing class groups assumed different responsibilities for a group project in-class (Persellin & Daniels, 2015). The group project was designing a cleanroom, accounting for human factors, HVAC, and environmental criteria. Criteria required communication between members of different responsibilities. Finally, there was class discussion that included review of the cleanroom solutions and reflection on the importance of leadership to group success. The researcher also acted as the class instructor during the pilot intervention.

The pilot study used a pre- / post-survey comparison to measure leader identity change due to the intervention. The survey consisted of demographics and leadership-based 5-item Likert questions predominantly from two identity-based constructs: Wielkiewicz's (2000) LABS III and the PCIR construct measures (Godwin et al., 2013). In addition, items were used to measure changes related to the LID Model (Komives et al., 2006). These measures provided insight into student response to a short-term identity-based leadership intervention (Hughes et al., 2020). A nonparametric binomial sign test was used to detect difference in survey responses between the pre-survey and post-survey. This test was chosen due to its relative robustness to small sample populations and multiple tied entries, as long as tied entries are not overly common (J. Cohen, 1988; Todman & Dugard, 2001, pp. 9-11).

3.4.1. Pilot Results

The pilot study results provided insight into what to expect from a similar intervention and also helped to trial execution of the intervention. Results from the pilot study were promising regarding the intervention's effectiveness, as evaluated by a nonparametric binomial sign test. Students increased significantly ($\alpha = 0.05$) in their belief that they could lead relationally ($B(10, 13, 0.5)$, $p = 0.047$) and that others saw them as leaders (($B(5, 5, 0.5)$, $p = 0.031$). The results also suggested increased belief that leadership is important to engineering, increased interest in developing leadership, and increased self-confidence in leadership (nonsignificant *p*-value, but large effect sizes, $g > 0.25$). Effect size in sign tests is an indication of how much differences diverge from a 50:50 split. In this case, effect sizes of greater than 0.25 indicate more than a 3:1 ratio between positive to negative sign changes (J. Cohen, 1988, pp. 147-150). Interestingly, students conversely reported negligible change in interest in learning about leadership, reflecting its experiential aspect (Hughes et al., 2020).

The pilot study provided insight into approximate effect sizes that could be anticipated in this research (Hughes et al., 2020). The goal sample size for this research was based on the pilot question least impacted by the intervention (as it would be the most conservative estimate), resulting in a sample size of 49 for question #8, or approximately 50.

A three-step process was used in this power analysis to identify required sample sizes based on pilot retrospective power analysis. First, the effect size (g) of the pilot

intervention items was calculated, based on a nonparametric binomial sign test, Equation B (J. Cohen, 1988, p. 147).

g = |(directional sign changes / total changes) – 0.5| [Equation B]

Second, GPower (v. 3.1.9.3) was used to identify required sample size, given defined α and β criteria, two-tailed testing, and an exact binomial statistical test. Finally, the factors used for this research are listed according to corresponding pilot items where applicable, in Table 5. This provided an estimate for the sample size required for this research, given typical maximum error thresholds (Type I, $\alpha = 0.05$: Type II, $\beta = 0.20$) levels. While criticisms of this approach exist due to differences between sample and population distributions, the paucity of research on this topic renders a priori effect size estimates (which are suggested) less reliable than empirical results (Faul, Erdfelder, Lang, & Buchner, 2007). Only sample population results for pilot questions that substantially overlap with the corresponding research factors are included here. Variation in sample sizes calculated exists due to substantial differences in effect size and variance.

3.4.2. Study Refinement Due to Pilot

Several changes were made to the pilot to better address the research purpose of this study. First, the intervention itself was modified. Four key changes to the pilot activities were made to improve this research. First, the intervention did not include a dedicated group project component. While the intervention included a group component, the function of the group was more for feedback and reflection than to submit a deliverable. This change facilitated implementation by simplifying the intervention. It

also limited the scope of the intervention, which enhanced focus on the most impactful aspects of identity-based instruction. These changes made the intervention much easier to integrate with existing course curricula.

Table 5: Power analysis pilot results (based on $\alpha = 0.05$, $\beta = 0.20$, nonparametric binomial sign test).

Research Variable	**Pilot Question**	**Effect size, g**	**Sample size**
Leader identity	#10, *Others see me as a leader*	0.50	6
Leadership Construct (OTL-Shared)	N/A	N/A	N/A
Leadership Construct (OTL-Development)	N/A	N/A	N/A
Leadership Construct (OTL-Power)	#8, *The main tasks of a leader are to make and then communicate decisions*	0.20	49
Leadership Construct (ELR)	#2, *Leadership is important to engineering*	0.25	30
Control, Interest	#4, *I am interested in developing leadership*	0.33	17
Control, Self-efficacy	#9, *I can be a leader, even if it is not my title*	0.27	25
Control, Engineering Identity	N/A	N/A	N/A

Second, a reflective component was added to the intervention, making the experience more personal, thereby providing more insight into how the intervention impacted participant self-identity. Third, activities were added to cultivate a more inclusive and engaged group environment. The lower-division intervention (three-step interview) had an activity that promoted diverse perspectives and interaction with others (Barkley et al., 2014, p. 121). The upper-division students had an activity (round robin) that promoted diverse perspectives and inclusive group work (Barkley et al., 2014, p.

108). Finally, additional reflection and goals outside of class were added. These promoted student agency and peer learning.

In addition, several of the measures used in this study were different than the pilot measure, to more closely reflect the leader identity approach taken in this study. The pilot intervention used a 10-item measure of aspects of engineering leader identity. This measure was predominantly based on Wielkiewicz's (2000) LABS III and the PCIR construct measures (Godwin et al., 2013). The foci of these tests was re-evaluated after the pilot, and core measures that better supported an identity approach were adopted: the Orientation Toward Leadership (OTL) measure (Drath, 2001; Hiller, 2005) and the Leadership Self-Identity (LSI) measure (Epitropaki et al., 2017; Hiller, 2005). Nonetheless, the new measures did exhibit substantial theoretical overlap with the pilot measures.

In addition to changes to the core variables, several additional modifications were made to the measures used in this study. The main reason for the modifications is the shift in focus. The pilot study truly was exploratory, as we were most interested in how students responded to the initial 10 measures, and in how an identity-based intervention might work in the classroom. For the full research study, validated control variables were added, as the intent of this research was not only to detect changes but investigate possible mechanisms of those changes. In addition, several additional outcome variables were added, as they provided insight into important related changes that participants might report (based on the literature). Finally, the syntax of several items was edited to improve clarity. In summary, while the pilot measures provided adequate insight into

the types of changes that students reported due to a short-term intervention, their theoretical focus and empirical grounding (i.e., validation) were not fully aligned with this dissertation-level research.

3.5. Study Design

A correlational research methodology was used to measure leader identity changes due to reflexive leadership instruction. Correlational research involves "… determin[ing] whether , and to what degree, a relationship exists between two or more quantifiable variables" (L.R. Gay, 2009, p. 196). Surveys were used as the primary data collection tool. Experiment design, identity measurement and variables, and analysis techniques are included in this section.

3.5.1. Setting

Participants in this study were undergraduate engineering students at two western state universities. Both institutions have demonstrated interest in engineering leadership research. The intervention and corresponding research occurred during the Spring of 2021. Classes were conducted through a mix of in-person, on-line, and hybrid formats. The intervention was conducted in six engineering courses: three introductory engineering courses at two institutions were used for researching lower-division students; three upper-level engineering courses at a single institution were used for researching upper-division students.

3.5.2. Sampling

Participants were chosen using a criteria-based convenience cluster sampling approach. Courses with a group-based component (or capability) and some focus on leadership (e.g., in syllabus or course objectives) were identified. Group-based courses help cultivate identity through several mechanisms, such as providing an opportunity for upper-level students to interpret their leadership experience within a framework consistent with the engineering profession. The intervention also requires a group activity. Using courses with some aspect of leadership (either explicitly or implicitly, through highlighting the responsibility of engineering) ensured the research contributed to student learning related to the course. These two criteria were used to identify possible courses.

A total of 166 students participated (44 lower-division and 122 upper-division). While all participants engaged with some aspect of the research, participation in all components of the research was more limited: 84 (50.6%) participants fully and correctly completed the quantitative surveys (29 and 55, respectively); however, over 89% participated in at least one voluntary component of the research. 39 lower-division (89%) and 51 upper-division (42%) students completed all assigned assignments, providing the primary source of the qualitative analysis. Five ethnicities / races were represented: most students were white (86%) while Asian (6%) and Hispanic (6%) provided the majority of the balance. Eight majors were represented: the most common majors were Industrial (28%), Mechanical (19%), Chemical (15%), and Financial (13%). Figure 23 includes

summaries of gender, major, race, and class level distributions of the lower-division and upper-division sample populations.

From these identified courses, the researcher partnered with course instructors willing and able to support the research. The researcher used personal and professional connections at both institutions to facilitate access and support at both sites, introducing a convenience aspect to the sampling method. Within each course, all students were part of the intervention (assignments and classroom discussion), reflecting a clustered approach to sampling. All students in the six selected courses were invited to be a part of the research, by completing the measures.

Introductory engineering courses provide an opportunity to scaffold leadership in an engineering context, as students are quickly developing their perception of the engineering field and its values during this time. Moreover, they tend to include students from a wide array of engineering majors. All students in introductory classes were sophomore or below and categorized as lower-division. On the other hand, upper-division courses provided an opportunity to discuss leadership in more authentic contexts. Participants in upper-division courses were categorized as upper-division, even if they did not strictly meet that criterion (4 out of the 59 participants were one semester short of junior status). Where participants were enrolled in multiple courses included in the intervention (6 participants), they were treated as being enrolled in only one of the courses (hence only asked to participate in the research once).

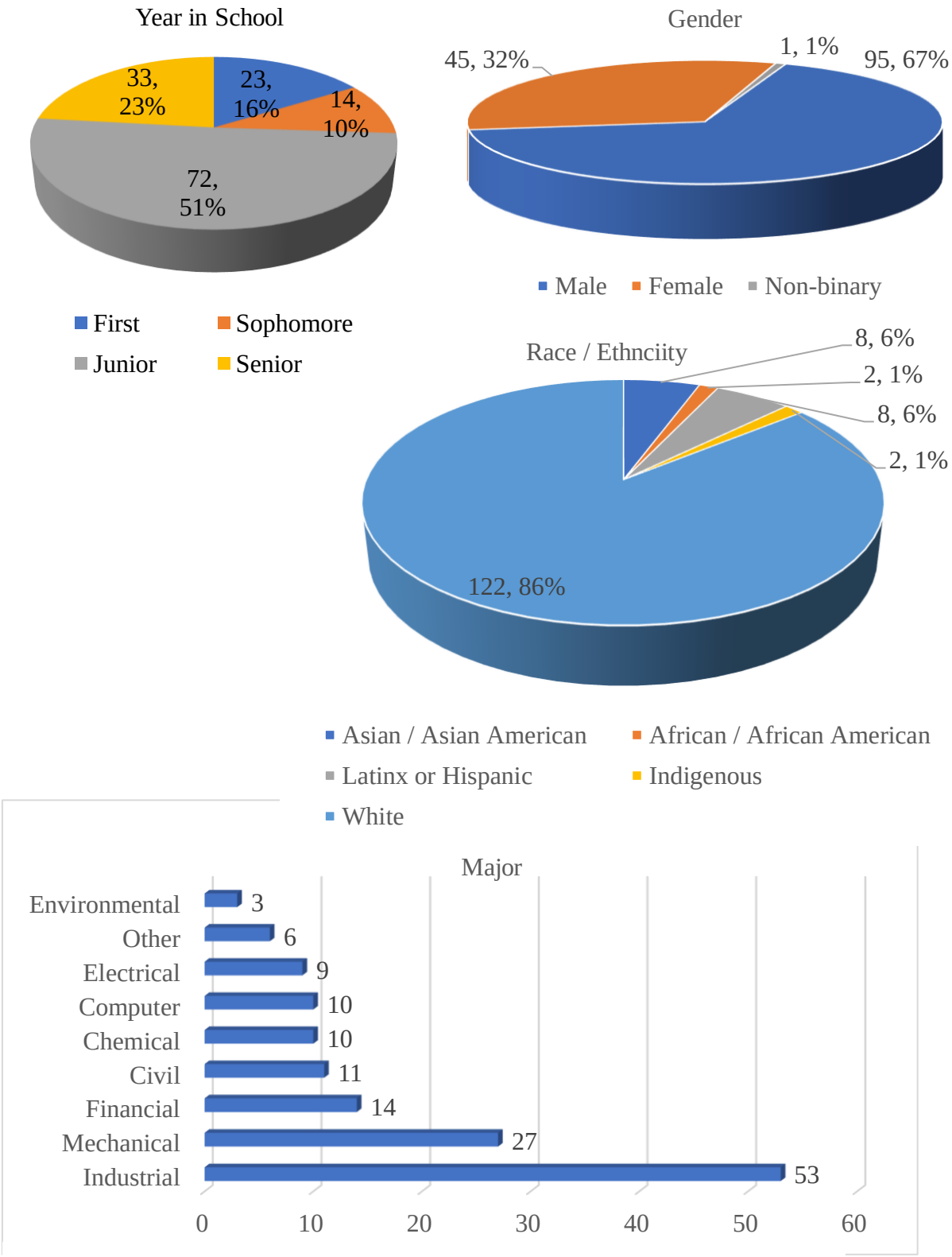

Figure 23: Participant demographics

The Montana State University Institutional Review Boards awarded exempt status to this research and approved the data collection procedure. Surveys were administered to all participants who submitted a consent form (Appendix Q), per IRB protocol (BT012621-EX), included in Appendix R. In addition, qualitative data in the form of class interactions and assignments (an outlook essay, reflective essay, and SMART goal essay [where applicable]) were memoed and archived for later reference. Qualtrics was used to administer the surveys and collect data.

The main incentive used to promote high participation in this study was extra credit for participation in the research and/or intervention. The conditions of the extra credit were at the instructors' discretion. It should be noted that reflective assignments and class attendance were all expected, as they supported course objectives. Several additional measures were taken to promote high participation and minimize attrition. First, instructor partners introduced the researcher to improve credibility of the research. Second, an introductory video to the research and its importance was assigned. Reminders were sent to individuals as due dates for responses approached. This was particularly important for upper-division students, as several weeks elapsed between the intervention and their reflective essay and following post-survey. Third, the researcher personally engaged with students at the first in-class (or on-line, where applicable) intervention to explain and to field questions about the research. Finally, the researcher followed up with participants to complete the post-survey.

Using this sampling approach, six courses were identified at two universities: three introductory engineering and three upper-division courses. The three introductory

courses in this study were the following: introduction to systems engineering (in-person, 95% industrial engineering majors); introduction to general engineering (in-person, various majors); and introduction to industrial engineering (on-line, demographic information not collected). Upper-division courses in this study included design of experiments (in-person, 75% industrial engineering, 21% financial engineering), capstone (in-person, 58% industrial, 38% financial engineering), and multidisciplinary engineering design (hybrid, 36% mechanical, 14% civil, 13% chemical and electrical engineering).

3.6. Data Collection

Quantitative data for this study were collected from a pre-survey and post-survey. The pre-survey was administered after the researcher was introduced to the class, but before the outlook essay was completed. The post-survey that was administered after the final reflective essay. See Figures 17, 18, and 23 for more details. The retrospective nature of the post-survey provided the basis of analysis to address the five research questions. Data for both the lower-division and upper-division participants were downloaded once the due date for the final reflective essay had passed.

3.7. Validity

This study addresses the research questions only insofar as the study design allows. This section addresses aspects of validity in the study design. Additional ethical validity concerns are included in the ethical considerations section (e.g., power

structures). Validity describes how well the research measures what it claims and how meaningful the findings are in other environments.

3.7.1. Internal Validity.

"Internal validity is the degree to which observed differences on the dependent variable are a direct result of [the intervention], not some other variable" (L.R. Gay, 2009, p. 242). While several steps to mitigate biases have been outlined thus far in the Methods chapter, there is no claim that those actions are comprehensive; there are additional ways in which internal validity may be compromised. First, several time-based phenomena may influence variables of interest during the intervention, such as history (the occurrence of influential events) or maturation (physical, emotional, or intellectual personal growth). For the lower-division intervention, these threats are expected to be minimal, as the intervention only lasted one week.

For the upper-division intervention, these concerns may be more relevant, as the better part of half a semester elapsed between the beginning and end of participation involvement. The essays provided insight into mechanisms and conditions of change, which helped mitigate concerns about unknown history. However, maturation may be a concern. While not expected to be important during the shorter lower-division interventions, the impact of maturation may compromise study validity for upper-division participants. Again, essays provide insight into influences on participation maturation and perspective shift. However, even using this triangulation approach, the impact of student maturity on response could artificially inflate self-report of growth due to the

intervention. Future work could leverage a control group and would do much to alleviate this concern.

Another concern regarding internal validity relates to the measures used. While concerns about response-shift bias have already been addressed largely by using a retrospective post-survey, there is always concern about unreliability of a measure. Several actions were taken to address this concern. First, validated measures were primarily used as sources for the surveys. Where such measures did not exist, items were based on similar validated measures and grounded in the literature. Second, raw results were reviewed for inappropriate responses (e.g., responses of only one value or incorrectly answering control questions). Third, the survey length was kept as short as possible to minimize survey fatigue (by primarily using direct measures). Fourth, electronic surveys were administered to minimize risk of transcription error. Finally, the pre-survey and the BEFORE component of the retrospective survey was compared for core variables: this comparison verified the relationship between them, while also checking for abnormal response trends. Leader identity retrospective response averages were within 2.3% of the pre-survey response averages. Leadership construct retrospective responses generally reflected larger changes than direct pre-survey to post-survey comparisons, while the difference in scores varied by an average of 11%.

Sampling bias (or self-selection bias), on the other hand, may be problematic, given only 50.6% completed the final survey properly. While several efforts were made to promote participation, it is unknown if there are any systemic trends related to those who failed to complete the final survey-- a concern with all studies with less than 100%

participation. Interaction with students from two of the upper-division classes indicate that the high mortality rate for upper-division students was likely due to the end-of-semester workload combined with the long time period between the intervention and post-survey: mortality in these two classes alone accounted for 85% (56 out of 66) of students who did not complete the final survey. Further analysis compared completers with non-completers (of the retrospective survey) in the class with the greatest mortality. This analysis showed that there were no gender, major, or race differences between those who completed the surveys and those who did not, once Bonferroni corrections were applied ($\alpha = 0.017$) (Appendix T). Despite these checks on self-selection bias, it is unknown how this influence impacted survey results. It is not unreasonable to expect that those students most impacted by the intervention would be most motivated to fill out the measures, introducing a positive bias to the results. Future research that introduces special incentives for participation after a long hiatus (and at the end of the semester) may be helpful in raising completion rates, thereby reducing the impact of this sampling bias.

Social-desirability may also play a part in survey completion, as students may want to be looked upon favorably by the researcher or instructor. While this type of bias is not problematic if it motivates students to fill out a survey, the bias may lead participants to artificially inflate the growth experienced due to the intervention (in order to be viewed favorably). While efforts were made to mitigate this concern (e.g., emphasizing the importance of honesty over 'correct' answers; emphasizing the confidentiality of the surveys), several additional measures would be recommended in

subsequent studies. First, using a quasi-experimental double-blind approach with a control group would address social-desirability bias, as all participants should exhibit this bias similarly. Second, a social-desirability scale may help understand and quantify this bias. The cumulative impact of these influences may introduce positive bias into all the results, thereby compromising the findings. In summary, sampling bias introduces uncertainty into the nature of the participants sampled. While subsequent action did not uncover any systemic concerns in this study, it is recognized that biases can be difficult to identify due to their influence on the very fabric of the research. Specifically, these biases may have impacted results, making the intervention appear more effective than in actual fact. Subsequent research in other environments, using some of the countermeasures suggested here would go far in addressing this concern.

Due to the limited sample size, a final sampling concern is sampling error, where the sample is improperly represented on a particular variable. To get an estimate of sampling error, outcome variable averages were compared by course, to check for homogeneity between courses (this approach has the advantage of data splitting techniques, with the added benefit of detecting potential unexpected differences between courses). No differences were found between courses (Appendix T).

However, just because no differences between courses were observed, that does not mean that pooling students across courses did not introduce validity concerns. There may be a number of environmental impacts that varied by course. These could be subtle enough to avoid detection in this limited study yet emerge as important in larger studies. Or the effect of these environmental impacts may only surface over long-term

development. One common approach that could help future research avoid this concern is hierarchal linear modeling, where the impact of individual groups may be isolated from other analysis.

The difficulty of not fully understanding the influences of various environments on participants is a common challenge in education research. On one hand, by not controlling the environment, a myriad of uncontrollable influences enter the research domain, possibly influencing results by either hiding intervention impacts or producing false effects. On the other hand, controlling the environment imposes artificial constraints on the research. This may actually hinder generalizability to many other environments that don't exert such control (Tashakkori and Teddlie, 2010). This balancing act is recognized as a fundamental challenge to research in any type of authentic setting (e.g., the classroom). It is hoped that future research will support the findings reported here, as the conditions under which student development occurs may be understood more fully.

The varied nature of student age in the interventions may lead to additional maturation influences (i.e.., taking 6 years instead of 4 to complete degree) that the existing measures cannot capture. This is particularly true for upper-division students, as taking four years is becoming increasingly less common. In other words, the combination of age and program status may combine in complex ways during development. This research asked about expected graduation date, which only precisely reflects lower-division and upper-division standing when exactly four years are taken. Tempering this concern is the shared technical training that upper-division students have

enjoyed. The only students to qualify for taking these upper-division courses are those who have had substantive experience in college already. Hence, it is reasonable to expect that these students have enjoyed many of the developmental benefits of college attendance, even if their age and class standing differ.

There is a second threat to validity relating to maturity. The survey questions about class standing do not address age, which is a component of maturation. Several students who were part of the research did not follow a 'traditional' pathway (i.e., attending college immediately after high school), which may introduce additional variables related to student maturity. While control variables related to leadership experiences help address important experiences that often accompany older students, continued progression in adult development would be expected to impact their experience. This is especially important for lower-division students, who are (by definition) less experienced with leadership. Conversely, students who are atypically young (due to AP credits or skipping grades) may also react differently to this intervention.

Finally, the nature of an inquiry into identity threatens internal validity. Because identity is a deep construct of human perspective, any attempts to capture or quantify it are difficult and risky, at best. In other words, the same characteristics that make identity a useful lens for understanding leadership development—dynamic, individual, complex, non-linear—also make it difficult to assess. For example, emotional maturity may very easily influence results, yet no controls were used for this expansive aspect of human behavior. As a result, any conclusions must be tempered by the tentative nature of our

actual understanding of participant identity measures. Nonetheless, it is hoped that a brief, surface-level inquiry into the impact of leader identity will provide a starting point for further research into how to best cultivate it.

3.7.2. External Validity

"External validity… is the degree to which study results are generalizable" (L.R. Gay, 2009, p. 242). The biggest threat to generalizability was the high number of industrial engineering majors. Industrial engineering majors demonstrated differing leadership interest, possibly due to selection into the major and possibly due to socialization during schooling. Hence, there may be unmeasured personal characteristics that both contribute to selection of industrial engineering and interest in leadership. In addition, there is some evidence to suggest that the industrial engineering field may be more advanced regarding leadership training and development (Handley et al., 2021).

Because major was included in the surveys, it was included as a control variable in regression-based models: the analysis found no differences by major. However, the limited number of participants in each major makes Type II errors more probable (e.g., 9 electrical and 11 civil engineering majors participated). This is a common challenge with small sample sizes and multiple levels of categorical variables (Stevens, 2012). As a result, impact of major on relevant outcome variables may not be completely detected by this research. This may compromise the generalizability of the research in two ways. First, differences between majors may be important and not detected in this research, due to low sample size in the subpopulations. Hence, specific other majors may respond differently to reflexive instruction in ways that are not observed here. Second, the overall

pooled results may not reflect the distribution of engineering majors in the United States, due to the high concentration of industrial engineers. This discrepancy means that overall programmatic initiatives may experience different results, given the differing distribution of majors. It should be pointed out here that pooling students by major is problematic in the first place, because it inherently obscures differences between students based on major. As noted previously, this is an important characteristic that should be explored in future research, so subpopulations have adequate sample size to avoid Type II errors when exploring the impact of major.

Even with controlling for major at the individual level, it is possible that a high percentage of industrial engineering majors in one class may impact participant experiences in unknown ways. For instance, if industrial engineering majors have had leadership training in management coursework, they may exercise stronger influence in their respective groups. Or, if they are perceived as those interested in non-technical aspects of engineering, other majors may defer to their opinions. In addition, industrial engineers may be susceptible to a selection-treatment interaction, where certain participants are impacted by the intervention in ways different than the general population.

To begin with, there are several concerns with the sampling approach used in this study that threaten efforts to generalize the findings. First, by choosing two western public universities (rather than a nation-wide research base) some demographic biases may emerge. The inclusion of demographic control variables for gender and race were intended to mitigate concerns about these impacts at an individual level. However, these

variables can make a difference at the institutional level, as gender and race trends have been shown to influence student experiences (e.g., Astin, 1993). This impact is expected to be minimal for gender, as both institutions have similar distributions to the national population. Nonetheless, this research may not be applicable to environments with gender distributions that differ greatly from the national average, as the influence of gender has been shown to impact engineers in multiple ways, at group and organizational levels (Faulkner, 2000)

In addition, the impact of race may influence results, as one university is predominantly white (87%) and the other is very diverse (e.g., whites account for 34% of the student population): the national average is 61% white ("College Students Are More Diverse Than Ever. Faculty and Administrators Are Not," 2019). While quantitative analysis showed no significant impact of this important characteristic on outcome variables (Appendix T), it is possible that the limited non-white population in the study increased the chance of making Type II errors in this analysis. In addition, difference in how races respond to the intervention may be obscured because minority groups were clustered for analysis, simply due to low sample sizes. Moreover, it is possible that race may have an impact on unmeasured mediating variables that could be important in long-term leadership development. The missing demographic information for one class is problematic, as the impact of these control variables is unknown for this class—especially since this was the most diverse subsection in the study. The lack of observed differences between the courses (Appendix T) suggest that racial representation rates (at a group level) may not have played a substantial role in participant response during this

research. Even with these checks on the influence of race, generalizability to institutions with high racial diversity amongst engineering students may be problematic, given the potential influence of race on various education outcomes in college {e.g., critical thinking skills, Pascarella, 2005 p. 199). Generalizability to other predominantly white institutions may be less problematic. Further research of a more diverse group of engineering students would address concerns about low power for detecting race-based differences. In addition, implementing this intervention in minority-serving institutions would do much to address concerns about how well this research is generalizable to minority groups at the individual, group, and organizational levels.

In addition, the novelty effect may have positively influenced participant interest in the material simply because it was different. The novelty effect describes participant positive regard due to novel circumstances or environments. There is limited concern over this effect, as the goal of the research is to measure the impact of a particular intervention that is abnormal by very nature. In other words, this (beneficial) effect will be just as relevant in any environment in which the intervention is enacted. On the other hand, the elevated impact due to the novelty effect may lead to artificially elevated reports of change in the measures, which would lead to increased Type I error rates. In addition, the impact of this effect may be problematic in generalizing these findings in education environments that already have leadership initiatives or programs. In other words, those environments may not see similar results simply because different ways of engaging the topic of leadership are commonplace, so the novelty effect is not a factor.

Finally, it should also be noted that convenience sampling, which introduces concerns about biases (especially when conducted without other sampling criteria), also maximizes the amount of research that can be accomplished with whatever limited resources a research project has (e.g., time or money). By leveraging convenient opportunities, researchers have opportunity to ask more research questions, engage with more participants, and get support from more colleagues: convenience empowers researchers to conduct riskier and richer research (L.R. Gay, 2009). Hence, this approach can be important for taking initial steps in fields of research that are less developed.

3.8. Procedure

Around the beginning of the Spring 2021 semester, the study approach and details were shared with various instructors who might be able to support the research. In the end, five instructors agreed and were provided with necessary documentation and resources to implement the intervention, including additional support from the researcher. Institutional Review Board (IRB) exempt approval was obtained. An overall timeline for the completed work is outlined in Figure 24.

At the beginning of the intervention during Spring 2021, the instructors introduced this study, and a brief video communicated the value of participation. Students were asked to complete an IRB-approved consent form. Those that consented were asked to complete the pre-survey via Qualtrics (with identifying information). All students were assigned the Outlook Essay: instructors were provided a PowerPoint to communicate the assignment (Appendix J). Completion of the essay and pre-lecture

videos were expected by the discussion class period. In-class activities, discussion, and concluding remarks took the entire class period. For upper-division students, approximately 20 minutes of a second class period was also required to discuss SMART goals.

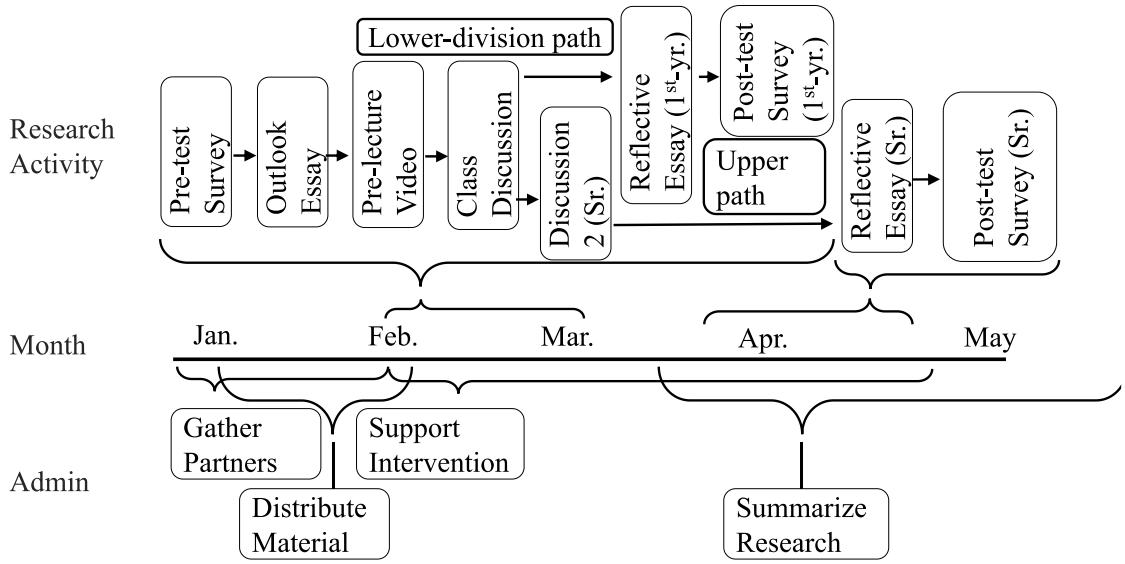

Figure 24. Research timeline.

For lower-division students, the reflective essay was assigned after the in-class activities, due one week later. For upper-division, the reflective essay was assigned after the second in-class activity, due at least six weeks later. The additional time provided opportunity for participants to pursue practical steps. Providing the assignment at least six weeks before the due date clarified the expectations of their personal reflection and actions.

Finally, the post-survey was administered to study participants. Both groups of participants were asked to complete the post-survey (via Qualtrics) after submitting the reflection essay. The times of completion differed between the two groups, due to the

difference of the reflection essay deadline. Identifiers in the survey allowed the researchers to pair post-surveys with pre-surveys. Identifying information was not shared outside the research team, per IRB protocol and respect of confidentiality.

3.9. Analysis

3.9.1. Quantitative

Raw quantitative data was collected from Qualtrics. Preparing the data for analysis involved eliminating unreliable data (e.g., students who incorrectly answered attention questions, gave uniform responses, or skipped sections). Outliers were reviewed for validity and removed when required, as noted previously. Data was then imported into Minitab (v19.2020.2.0). Next, descriptive statistics were calculated. Analysis involving any statistical tests began with verification that data met assumptions. Any deviations from these assumptions are noted, along with steps taken to address them. Factor loadings were calculated for study validation, where applicable. Power calculations were made using G-power (v3.1). Post-hoc calculations identified the power achieved, given sample sizes used, effect sizes achieved, and Type I error thresholds (including family-wise error corrections, where applicable). Finally, analysis was conducted to test each of the six hypotheses (Table 2), using an α-level of 0.05 (two-tailed). Detailed approaches to each analysis are presented with the respective hypotheses, below.

3.9.1.1. Missing data.

Missing data was handled by pairwise deletion, under the assumption of Missing Not at Random (MNAR). MNAR indicates that the cause of

missing data is due to unobserved data (J. W. Graham, 2009). This assumption was adopted since it is possible that participants with decreased interest in leadership will be less inclined to complete the surveys. This means that missingness may not be at random. While this condition leads to parameter bias, the bias amount is a function of the amount of missing data; in other words, more missing data indicates more bias. One guideline is that listwise deletion of about 5% of the data cases results in practically negligible parameter bias. Likewise, pairwise deletion in similar situations tends to incur small biases (J. W. Graham, 2009). While missing data rates varied based on the statistical test performed, the overall missing data amount was extremely low (0.04%).

3.9.2. Hypotheses 1L/1U

RQ1: Does reflexive instruction about engineering leadership influence leader identity?

$H1L_o$: Reflexive instruction about engineering leadership does not influence leader identity of lower-division students.

$H1U_o$: Reflexive instruction about engineering does not influence leader identity of upper-division students.

These hypotheses address Research Question 1: Does an identity-based intervention influence leader identity? Lower-division and upper-division participant responses was analyzed to test H1L and H1U respectively (where applicable). The "core leadership self-identity factor" total measured leader identity. The analysis used a paired t-test comparing retrospective (BEFORE) with NOW post-survey results. Hypotheses using a "L" indicate those relevant for lower-division students; those using a "U" indicate

upper-division students, typically. Table 2 includes comparisons between the research questions and hypotheses, as previously outlined in the end of the Literature Review chapter. Finally, factor items were evaluated to identify their reliability with the LSI composite measure in this data set: Cronbach's α for lower-division students was (n=27) 0.96; for upper-division, (n=51) 0.93.

3.9.3. Hypotheses 2L/2U

RQ2: Does reflexive instruction about engineering leadership influence engineering leadership construct?

$H2L_o$: Reflexive instruction about engineering leadership does not influence engineering leadership construct of lower-division students.

$H2U_o$: Reflexive instruction about engineering leadership does not influence engineering leadership construct of upper-division students.

These hypotheses addressed change in leadership construct, as defined by the three Orientation toward Leadership (OTL) factors (process or Shared, development or Influence, and power or Dominance) and the Engineering-Leadership Relationship (ELR) measure. Each of these four factors was analyzed with a paired t-test, between retrospective (BEFORE) and NOW post-survey results: the same process as with Hypothesis 1. A Bonferroni correction accounted for family-wise error due to the inclusion of four factors (J. P. Stevens, 2012, pp. 6-8).

Finally, factor items were evaluated to identify how well they aligned with their respective factors. Cronbach's alpha for the dimensions of OTL were all above a cutoff of 0.7, except for the Power factor. The power factor had a Cronbach alpha of 0.43 for

lower-division students, 0.61 for upper-division. While these amounts are outside of typical minimum standards, low number of items and small sample sizes are both known to increase the range of acceptable Cronbach's alpha (Bonett & Wright, 2015). Moreover, the Cronbach alpha of interest is that which exists in the population, rather than the research sample: this metric has already been used to validate the internal consistency of the measure in much broader populations (Bonett & Wright, 2015; Hiller, 2005). Nonetheless, this discrepancy does merit further research: is it due to the nature of this limited study, due to the refinement of the Power-based measure, or due to unique characteristics of engineering students? Finally, the correlations between leadership construct factors echoed those calculated in the original instrument validation (Hiller, 2005). The correlation similarities reflect consistency between the study population and other populations; they also suggest minimal loss in model structure due to refinement of the measures.

3.9.4. Hypotheses 3L/3U

RQ3: Does engineering leadership construct influence leader identity?

$H3L_o$: Engineering leadership construct does not influence leader identity of lower-division students.

$H3U_o$: Engineering leadership construct does not influence leader identity of upper-division students.

These hypotheses directly addressed the relationships between leader identity and engineering leadership construct. Correlation analyses and multiple linear regression models were built to explore these relationships (Equation C). Regression models

identified simultaneous and unique contribution of all four leadership constructs on LSI (of BEFORE retrospective self-assessments). The first models included the main leader identity indicator and the four leadership construct predictors. The BEFORE post-survey engineering leadership construct factors (OTL-process [x_1], OTL-development [x_2], OTL-power [x_3], and ELR [x_4]) were the regressors. The regressand was BEFORE post-survey leader identity (LSI core identity factor [y]). These regressors and regressands were chosen to reflect the causal relationship implied by the research question. Moreover, retrospective BEFORE self-assessment was chosen because the main interest of this hypothesis was to explore student perception prior to the intervention: the impact of the intervention is captured in Hypothesis 4. This approach allowed analysis to identify the relative impact of the leadership construct factors (if any) on identity leading up to the intervention, independent of any changes that participants reported.

Subsequent analysis implemented a stepwise regression approach. This approach explored the data with more granularity while mitigating the adverse impact of unnecessary control variables on model degrees of freedom, when appropriate care is taken (P. Cohen, West, & Aiken, 2014; J. P. Stevens, 2012). Control variables (e.g., leadership alignment with program) [$x_{5...}$] were stepwise added to the leadership construct variables in two sequential groups (experience then demographics), using sequential sum of squares (Equation D). The sequential approach foregrounded experience, due to its relatively higher expected impact on leader identity, following a sequential model based on variables of interest. By prioritizing causally proximal variables, this approach mitigates positive bias from spurious variables (such as race and

gender) that may be influenced by unmeasured control variables (P. Cohen et al., 2014, p. chapter 12). The final model used adjusted sum of squares to identify unique partial contributions to explained variance. Stepwise parameters included OTL, ELR, and any previously included regressors in every model, while testing for influential control variables, $\alpha_{\text{enter}} = 0.1$, and $\alpha_{\text{remove}} = 0.2$. For experience variables, Position was regressed first; if significant, follow-up regression included variables related to leadership experience. This step was implemented to address the conditional nature of the leadership experience variables: they were only measured when a participant had indicated previous leadership experience. Finally, the addition of variables into the stepwise regression approach was subject to considerations of theory, power and multicollinearity requirements (J. P. Stevens, 2012, pp. 61-62).

$$\mathbf{Y = B\,X + E} \qquad \text{[Equation C]}$$

$$Y_{\text{LSI factor}} = \beta_0 + \beta_1 * x_1, \; + \beta_2 * x_2 + \beta_3 * x_3 + \beta_4 * x_4 + \beta_5 * x_5 + \ldots \; + \varepsilon \qquad \text{[Equation D]}$$

Except where noted otherwise, regression assumptions were satisfied via residual analysis, including tests for normality, outliers, leverage points, and multi-collinearity. These tests were especially valuable, given the low sample sizes (between approximately 27 and 51) upon which the regression models were built. Variables with high VIF values (>10) were removed to avoid issues with multi-collinearity, which can be especially

problematic while evaluating models with many regressors: high n/k ratios can lead to breakdown of regression model assumptions.

Table 6: Multiple linear regression variables.

Coefficient	Variable
[y]	Core LSI factor
[x_1]	OTL-Process factor
[x_2]	OTL-Development factor
[x_3]	OTL-Power factor
[x_4]	Engineering Leadership Relationship
[$x_{5....}$]	Controls (experience and demographics)

3.9.5. Hypotheses 4L/4U

RQ3: Does engineering leadership construct influence leader identity?

$H4L_o$: Change in engineering leadership construct does not influence change in leader identity of lower-division students.

$H4U_o$: Change in engineering leadership construct does not influence change in leader identity of upper-division students.

These hypotheses required a similar approach as H3. However, the multiple regression model used the *difference* between the BEFORE and NOW post-survey responses in leadership construct as the regressors (of the same four variables as in H3). Similarly, the regressand was *change* between BEFORE and NOW post-survey leader identity. Using the difference as a measure of interest (rather than measuring NOW,

controlling for BEFORE) foregrounded the changes in perception that the participants reported (Rohs, 1999). This analysis identified the impact of a *shift* in leadership construct on leader identity *change*. As in H3, a two-staged multiple regression approach was used: leadership constructs as regressors, followed by a stepwise approach. In addition, by comparing coefficients of the regression equation, this analysis identified the relative descriptive impact of construct shifts on leader identity change.

3.9.6. Hypothesis 5

RQ4: Does reflexive instruction about engineering leadership influence lower-division students' leader identity differently than it influences upper-division students' identity?

$H5_o$: Reflexive instruction about engineering leadership does not influence lower-division students' leader identity differently than it influences upper-division' identity.

This hypothesis compared lower-division change in leader identity with upper-division change. Leader identity change was defined by the difference between BEFORE and NOW post-survey responses. ANCOVA was used to compare these two groups, with the dependent variable of interest being leader identity change. Covariates included influential control variables, as defined by those that emerged as important during previous analysis (H3x and H4x). A subsequent MANCOVA model explored the two factors of the dependent variable separately (descriptiveness and importance), to measure how different student groups may respond to different aspects of leader identity.3.9.7.

3.9.7. Hypothesis 6

RQ5: Does reflexive instruction about engineering leadership influence lower-division students' engineering leadership construct differently than it influences upper-division students' construct?

$H6_o$: Reflexive instruction about engineering leadership does not influence lower-division students' engineering leadership construct differently than it influences upper-division students' construct.

This hypothesis compared lower-division and upper-division change in leadership construct. MANCOVA was used to compare these two groups, as the dependent variable of interests (construct) has four factors that cannot be sensibly consolidated. Leadership construct change was defined by the difference between BEFORE and NOW post-survey responses of the four respective leadership construct measures. As in Hypothesis 5, covariates included influential control variables.

3.9.8. Other Outcome Variables

Analysis also included exploration of changes in other outcome variables. This analysis fulfilled a supporting role in triangulating and interpreting core quantitative analysis. Change in these measures (between BEFORE and NOW post-survey) was of particular importance. These outcomes include interest in developing as a leader, self-efficacy in exercising leadership, and identity as an engineer. While these did not directly address the research questions, they were used to further understand and to interpret analysis results.

3.9.9. Qualitative

To support valid interpretation of quantitative results, qualitative data were reviewed and integrated into interpretation. In other words, the basic study design used qualitative data to interpret quantitative findings, per Figure 20. The qualitative data provided insight into the mechanism, causes, and details of relationships of interest. Relevant findings from the qualitative data are included in the respective Results sections. Here, the reader is reminded that this research is quantitative in nature, and that qualitative data is only used to augment interpretation of the quantitative analysis. This approach supported a robust examination of the research questions.

Qualitative analysis consisted of several stages to allow themes in participant responses to emerge. First, passages from the assignments were categorized according to the research questions they addressed. This roughly followed a variable-oriented analysis, where emergent themes are organized around prescribed ideas (Tashakkori & Teddlie, 2010). Line-by-line coding was used to categorize data into the research question that addressed them. From there, codes were reviewed and iteratively grouped based on emergent themes. These themes were finally summarized in their own memo. In addition, crosstab queries focused on qualitative categories prominent in relationships (such as between lower-division students and leader identity change).

Several additional procedures were borrowed from qualitative methods. For example, queries compared the frequency of discussion of concepts (from qualitative essays) with reported effect sizes (from quantitative surveys), thereby checking reported relative impact of the intervention. Negative cases were specifically highlighted to

temper any positive biases, as well as highlight conditionalities that may exist. The essays of participants with outlying responses were investigated to identify the source of the discrepancy (e.g., was an extreme response given due to improper survey response or an extreme experience)? Peer debriefing provided an opportunity to check for researcher bias, as well as critique operationalization of the intervention. This was conducted after several interventions by getting feedback from course instructors who were present during the intervention. Field notes provided an additional resource for confirming student perspectives and for checking researcher observations during the intervention timeframe. Finally, due to the quantitative nature of the research surveys and general preference for quantitative methods in STEM research, a postpositivist epistemology and methodology drove qualitative aspects of the analysis, discussion, and any implications for practice (J. W. Creswell, 2013, pp. 36-37).

Findings from the qualitative data are included in the latter part of the Results chapter. Emergent themes from this data are furthermore integrated into the Discussion chapter.

3.9.10. Summary

The analysis plan addressed each of the six hypotheses, using multiple analytical techniques. These tests provided insight into the various ways reflexive instruction on engineering leadership might impact identity and leadership constructs: self-descriptiveness, importance, leadership as process, leadership as learned, leadership as power, or the relationship between engineering and leadership. Additional control

variables provided additional insight into the impact of the intervention, in ways in which the literature is not entirely definitive. A combination of the core and control variables provided results that further our understanding of how leader identity develops.

3.10. Ethical Considerations

The most significant ethical complication was the researcher's role as moderator of leadership discussion and grader of related assignments. This introduced a power structure into an apparently honest discussion which may have compromised participant willingness to share openly (Miles & Huberman, 1994). In addition, there was one class where the researcher also acted as the course instructor. This was a second condition in which a power structure may have influenced participant response. The adverse impact of a power structure was addressed by clarifying that grading for these activities was assessed only by completion: this standard was used in all participating courses. And, nonparticipation in the research did not adversely impact student grades. While non-participating students did not receive extra credit, this would only adversely impact student grades if overall class grades (as opposed to exam grades) were administered on a curve, which was not the case. To address any positivity bias, the researcher emphasized the151esearchh aspect of the class modules; in other words, the Importance of honesty (rather than correct answers) was emphasized.

A second ethical complication was the ability of the researcher to mediate discussion about leadership-related concepts or scaffold leadership behaviors, as this may have fallen outside of the researcher's expertise (Farr et al., 1997; R. Graham, 2012; R.

Graham et al., 2009). However, this impact was minimal: an area of expertise of the researcher is engineering leadership (so probably had an adequate knowledge to effectively discuss and scaffold various leadership models), and the researcher had experience as an educator (so had developed techniques to manage discussion and to provide relevant and accurate feedback).

The third ethical complication was the researcher's direct interaction with participants. This may have adversely influenced student honesty since they knew that the researcher had access to their responses, introducing confirmation bias or even social desirability bias. The researcher's contact with this group of students was minimal in five of the six classes, minimizing this concern. In five of the classes, the researcher was introduced by the instructor and ran the intervention for one or two class periods. For the sixth class, the researcher was also the instructor. During the intervention, the role as researcher (and not instructor) was explicitly highlighted at the start of class. Moreover, the researcher clarified in his introduction of the research that all identifying information would be removed once data was compiled, leading to confidential data. Additionally, the identifying information would only be used to pair surveys after the fact, so no one would be using this information for assessment purposes. Finally, IRB approval indicates appropriate measures were taken to minimize risk and potential ethical concerns (Appendices Q and R).

CHAPTER FOUR

RESULTS

This chapter addresses results from data analysis for each of the five research questions. Descriptive statistics will be presented first, followed by analysis results for each of the six hypotheses. Descriptive statistics for leader identity, leadership construct, and additional variables are included in Tables (Tables 7, 8, and 9). The six hypotheses predict relationships between various aspects of leader identity and leadership construct, including control variables. The results fully support Hypotheses 1, 2, and 4. Hypothesis 3 was marginally supported. Hypotheses 5 and 6 were not supported.

The analyses of the hypotheses first include core tests that directly address the hypotheses. The results of assumption tests (and any special action taken to address assumption violations) will also be included. Results from further exploratory analysis will be presented. The combination of these components provides transparency to the approach taken to address the research questions. Finally, correlations are included below to provide an overview of variable relationships (Tables 10 and 11).

Table 7: Descriptive statistics, leader identity, by class level

Variable	Class Level	N	Mean, BEFORE[1]	Mean, NOW	St Dev
Ldr Identity	Lower	27	3.867	4.500	1.622
	Upper	51	4.663	5.147	1.243
Ldr Identity: CHANGE	Lower	27	0.633	N/A	0.737
	Upper	51	0.484	N/A	0.754

Table 8: Descriptive statistics, engineering leadership construct, by class level

Variable	Class Level	N	Mean, BEFORE[1]	Mean, NOW	St Dev
OTL-Power	Lower	27	3.531	2.901	1.114
	Upper	55	3.145	2.551	1.018
OTL-Develop	Lower	27	3.676	4.320	0.935
	Upper	54	3.532	3.981	0.896
OTL-Shared	Lower	27	4.648	5.926	1.290
	Upper	55	4.709	5.564	0.777
Engr Ldrshp Relation	Lower	28	4.536	6.143	1.644
	Upper	51	4.706	5.595	1.432
OTL-Power: CHANGE	Lower	27	-0.630	N/A	0.912
	Upper	55	-0.594	N/A	0.867
OTL-Develop: CHANGE	Lower	26	0.644	N/A	0.858
	Upper	54	0.449	N/A	0.747
OTL-Shared: CHANGE	Lower	27	1.278	N/A	1.336
	Upper	55	0.855	N/A	0.875
Engr Ldrshp Relation: CHANGE	Lower	28	1.607	N/A	1.286
	Upper	54	0.889	N/A	1.127

Table 9: Descriptive statistics for experience and (numerical) demographic control variables, and other outcomes, by Class level (excluding race and major)

Variable	Class Level	N	Mean	St Dev
Leadership Interest	Lower	27	5.037	1.629
	Upper	51	5.235	1.423
Ldr Self-efficacy	Lower	27	5.037	1.786
	Upper	51	5.510	1.120
Engr Identity	Lower	28	4.607	1.707
	Upper	52	4.673	1.424
Position not held	Lower	28	50.0%	N/A
	Upper	52	7.7%	N/A
Program leadership overlap	Lower	14	2.429	0.938
	Upper	51	2.588	1.062
Leadership use in course	Lower	14	2.429	1.089
	Upper	50	2.540	0.862
Interact w diverse	Lower	14	3.214	0.975
	Upper	50	2.780	1.016
Female	Lower	21	23.8%	N/A
	Upper	53	39.6%	N/A

4.1. Hypotheses 1L/1U

$H1L_o$: Reflexive instruction about engineering leadership does not influence leader identity of lower-division students.

$H1U_o$: Reflexive instruction about engineering does not influence leader identity of upper-division students.

Hypothesis 1 predicted that the short-term intervention would impact students' leader identity, as measured by Hiller's leadership self-identity core measure (LSI). As demonstrated by Table 10, both lower-division and upper-division students reported significant increases in their leader identity. This data suggests support for the alternative hypothesis (at α–level of 0.05), providing evidence that reflexive instruction does influence leader identity in the positive direction, for both lower- and upper-division students. Table 7 lists corresponding descriptive statistics, including student average increases of 0.63 and 0.48 (units on a 7-level Likert-type scale for lower-division and upper-division, respectively). The respective effect sizes were 0.86 and 0.64. Absolute variable descriptives were calculated from BEFORE component of retrospective survey, where applicable. CHANGE variable descriptives were calculated by subtracting BEFORE component from NOW component of the retrospective survey, where applicable.

Normality assumptions of LSI scores were met for upper-division, using Ryan-Joiner test at $\alpha = 0.05$. This test was chosen over Anderson-Darling due to its relative insensitivity to tie scores, which can be common in Likert scaled data. Lower-division normality assumptions were not met, with the additional complication of two outliers

Table 10: *t*-test for change in leader identity

Hypothesis	*t*-value	Sample size	Effect size	95% CI	*p*-value
$H1L_a$: Change in LSI ≠ 0 for lower-division	4.46	27	.86	0.341, 0.924	**<u><.001</u>**
$H1U_a$: Change in LSI ≠ 0 for upper-division	4.58	51	.64	0.272, 0.696	**<u><.001</u>**

<u>Underlined</u> indicates significance at $\alpha = .05$; **bold,** significance at $\alpha = .001$

present (using Grubbs' Test). However, removal of the outliers resulted in meeting normality assumptions, without substantively influencing results (i.e., similar *p*-value), as the impact of outliers in this data was to artificially increase variance, leading to negative bias. In addition, qualitative data sources reflected the types of responses participants provided. Hence, outliers were included in analysis, as they did not impact results and they were confirmed by qualitative data. In other words, the influence of a negative bias introduced by data outliers was superseded by the value of keeping the data points. Moreover, keeping the outliers in-place served the same function as robust approaches to ordinary least squares models, as the data points are evaluated in such a way as to not adversely affect results (i.e., as a type of insurance policy) (P. Cohen et al., 2014, pp. 416-419).

Further exploration was conducted to identify which students might have been most influenced by the intervention. Correlation analysis that compared change in leader identity with absolute measures in other outcomes (i.e., interest, self-efficacy and engineering identity) found two significant relationships for upper-division students. Leadership interest (r (50) = -.454, p = .001) and self-efficacy (r (50) = -.535, p < .001)

were both negatively correlated with change in leader identity. No significant relationships existed for lower-division students.

Exploration of changes in other outcome variables showed that increases in leader identity was not the only outcome positively impacted. Participants also experienced significant increases in leadership interest, leadership self-efficacy, and engineering identity, per Table 11. Effect sizes for these changes varied from moderate (~0.50) to high (0.80), with the largest being 0.95.

Further exploration of the results identified how increases in these outcomes varied by participant characteristics. Correlation analysis between absolute scores and score changes showed two significant relationships between absolute scores and score changes. For upper-division students, those students with lower interest (r (51) = -.641, $p < .001$) and self-efficacy (r (51) = -.621, $p < .001$) before the intervention reported the greatest increases in interest and self-efficacy, respectively. There were no significant relationships for upper-division engineering identity or any lower-division comparisons.

4.2. Hypotheses 2L/2U

$H2L_o$: Reflexive instruction about engineering leadership does not influence engineering leadership construct of lower-division students.

$H2U_o$: Reflexive instruction about engineering leadership does not influence engineering leadership construct of upper-division students.

Hypothesis 2 predicted that the intervention would impact students' engineering leadership construct (Orientation to Leadership [OTL] and Engineering Leadership Relationship [ELR]). As detailed previously, OTL consists of three non-orthogonal

Table 11: *t*-test for change in other outcomes, by class level

Outcome	Population	t-value	Sample size	Effect size	95% CI	*p*-value
Leadership interest	Lower-division	4.91	27	.95	0.560, 1.366	**<.001**
Leader self-efficacy		3.70	27	.71	0.412, 1.440	**.001**
Engineering identity		2.75	28	.52	0.127, 0.873	.011
Leadership interest	Upper-division	4.72	54	.64	0.335, 0.850	**<.001**
Leader self-efficacy		4.62	54	.63	0.335, 0.850	**<.001**
Engineering identity		4.76	55	.64	0.347, 0.853	**<.001**

Underlined indicates significance at $\alpha = .05$; **bold,** significance at $\alpha = .001$

orientations, or factors: Power (OTL-P), Development (OTL-D), and Shared (OTL-S). Table 12 reports t-test results, with significant changes in all four aspects of leadership construct for both lower-division and upper-division students. These results provide evidence affirming the alternative hypothesis: reflexive instruction in engineering leadership influence engineering leadership construct for all students ($\alpha = 0.05$). One comparison failed the normality assumption (OTL-Power: CHANGE for lower-division participants). Further analysis identified two outliers in this comparison. One outlier was kept; while its removal did allow the data set to meet normality assumptions, removal did not substantively alter the findings. As addressed in Hypothesis 1 results, this process serves the same function as robust approaches to ordinary least squares models (P. Cohen et al., 2014, pp. 416-419). One outlier data point was removed from analysis after a comparison with qualitative data indicated that the respondent's survey response clearly differed from his retrospective essay. This approach conforms to standard remedial

action for outlier presence (P. Cohen et al., 2014, pp. 412-415). To address family-wise error, Bonferroni correction was made, resulting in $\alpha = 0.013$ ($\approx 0.05/4$) (J. P. Stevens, 2012, pp. 7-8).

Table 12: t-test for change in leadership construct, by class level

Hypothesis	*t*-value	Sample size	Effect size	98.7% CI	*p*-value
$H2L_a$: Change in OTL-P ≠ 0, lower-division	-3.59	27	-.691	-1.098, -0.162	**.001**
$H2L_a$: Change in OTL-D ≠ 0, lower-division	3.83	26	.751	.194, 1.094	**.001**
$H2L_a$: Change in OTL-S ≠ 0, lower-division	4.97	27	.956	0.592, 1.964	**<.001**
$H2L_a$: Change in ELR ≠ 0, lower-division	6.61	28	1.250	0.961, 2.254	**<.001**
$H2U_a$: Change in OTL-P ≠ 0, upper-division	-5.08	55	-.685	-0.894, -0.294	**<.001**
$H2U_a$: Change in OTL-D ≠ 0, upper-division	4.42	54	.581	0.188, 0.710	**<.001**
$H2U_a$: Change in OTL-S ≠ 0, upper-division	7.24	55	.977	0.551, 1.158	**<.001**
$H2U_a$: Change in ELR ≠ 0, upper-division	5.80	54	.789	0.495, 1.283	**<.001**

Underlined indicates significance at $\alpha = .05$; **bold,** significance at $\alpha = .001$

The quantitative results decisively demonstrated that the intervention had a significant impact on all aspects of participants' leadership construct. Student belief in the OTL-Power factor significantly decreased, while belief in the OTL-Development, OTL-Shared, and ELR factors significantly increased. Moreover, effect sizes were substantial (AVE $|\eta| = .835$), with OTL-Shared effect sizes approaching 1.0.

4.3. Hypotheses 3L/3U

$H3L_o$: Engineering leadership construct does not influence leader identity of lower-division students.

$H3U_o$: Engineering leadership construct does not influence leader identity of upper-division students.

Hypothesis 3 proposed that participants' engineering leadership construct predicts their leader identity (i.e., LSI). Correlation analysis (of BEFORE retrospective self-assessments) found mixed support for this hypothesis for lower-division and upper-division students. Engineering leadership relationship (ELR) was the only significantly correlated engineering leadership construct factor (r (27) = .483, p = .011; r (51) = .370, p = .008; for lower-division and upper-division students, respectively), per Tables 13 and 14. A Bonferroni correction was made to the α-level to correct for family-wise error (α = .013) (J. P. Stevens, 2012). In addition, subsequent models evaluated the impact of control variables on leader identity. Differences of leader identity between the six participating courses were explored. ANOVA exploration of the impact of Class on upper-division leader identity was non-significant. Finally, leader identity relationship with outcome variables was explored.

Initial regression analysis enabled identification of unique contributions from each regressor on the regressan. This approach found mixed significant relationships with LSI for lower-division and upper-division students (p = .099 and .047, R^2 = .29 and .19, respectively). Engineering leadership relationship was the only significant predictor

Table 13: Correlations among absolute variables and experience / demographic control variables, lower-division participants (excluding race and major)

	Ldr Identity	OTL-Power	OTL-Develop	OTL-Shared	Engr Ldrshp Relation	Position not held	Program ldrshp overlap	Ldrshp use in course	Interact with diverse
OTL-Power	0.208								
OTL-Develop	0.221	0.039							
OTL-Shared	0.202	-0.191	0.410						
Engr Ldrshp Relation	0.483	0.070	0.132	0.326					
Position not held	0.166	0.106	0.447	-0.282	0.199				
Program leadership overlap[1]	0.251	0.096	0.332	0.205	0.199	N/A			
Leadership use in course[1]	0.250	-0.040	0.611	0.623	0.360	N/A	0.409		
Interact w diverse[1]	0.191	-0.116	0.650	0.628	0.166	N/A	-0.108	0.414	
Female	-0.267	0.461	0.185	0.123	-0.059	-0.085	0.028	-0.159	-0.023

Underlined indicates significance at $\alpha = .05$; double underline, significance at $\alpha = .013$ (where applicable for Bonferroni corrections); [1]Minimum sample is 11, 20 elsewhere.

Table 14: Correlations among absolute variables and belief / experience / demographic control variables, upper-division participants (excluding race and major)

	Ldr Identity	OTL-Power	OTL-Develop	OTL-Shared	Engr Ldrshp Relation	Position not held	Program ldrshp overlap	Ldrshp use in course	Interact with diverse
OTL-Power	-0.213								
OTL-Develop	0.118	-0.055							
OTL-Shared	0.071	-0.197	0.193						
Engr Ldrshp Relation	0.370	-0.126	0.125	0.428					
Position not held	-0.290	-0.034	-0.075	0.071	-0.042				
Program leadership overlap	-0.362	0.238	0.019	-0.049	-0.048	N/A			
Leadership use in course	0.009	0.127	-0.237	-0.297	-0.026	N/A	0.406		
Interact w diverse	0.292	-0.023	-0.330	-0.023	0.153	N/A	-0.215	0.234	
Female	0.065	0.062	0.206	-0.041	-0.042	0.044	0.189	-0.170	-0.090

Underlined indicates significance at $\alpha = .05$; *italics*, significance at $\alpha = .013$ (where applicable for Bonferroni corrections); Minimum sample is 46.

of leader identity (b = .427, p = .032; b = .337, p = .011; for lower- and upper-division, respectively).

An inclusive stepwise regression model was subsequently developed that included demographic and experience control variables. Further discussion addressing the potential liabilities of this approach may be found in the Methods chapter and Limitations section. Summary information on the regression models may be found in Table 15. PRESS statistics are included to facilitate comparison of initial and inclusive models. The stepwise model was overall significant for lower-division students (p = .035, R^2_{adj} = .31): interacting with diverse others had a marginally significant positive coefficient (p = .092), per Table 16. Likewise, the inclusive model was significant for upper-division students (p = .003, R^2_{adj} = .25): interacting with diverse others and (mis)alignment of leadership experience with academic program were both marginally significant additions to the model (p = .097 and .061, respectively), per Table 17.

Table 15: Regression summary, predictors of LSI, by class level

Approach	Tactic	Class level	Controls	*p*-value	PRESS
Initial	Initial	Lower-division	None	.099	76.0
Inclusive	Stepwise	Lower-division	Interact w diverse	<u>.035</u>	67.7
Initial	Initial	Upper-division	None	<u>.047</u>	78.9
Inclusive	Stepwise	Upper-division	Interact w diverse, Program leadership overlap	<u>.005</u>	64.9

<u>Underlined</u> indicates significance at α = .05

Initial analysis of the impact of major on lower-division leader identity (during stepwise regression) indicated that the relationship was non-significant (p = .075).

However, given the strength of this relationship, it was further parsed out through ANOVA: industrial engineering majors reported higher LSI scores (than computer science and undeclared majors) according to Fisher pairwise comparison (which has a positive bias dependent on familywise error related to six majors evaluated). However, controlling for leadership interest—a relevant control that may correspond with major selection—eliminated the significance of the influence of Major (Table 18). This relationship is pursued more in-depth during analysis of the differences between lower-division and upper-division students (Hypotheses 5 and 6).

Finally, relationships between outcome variables were explored: leader identity, leadership interest, leadership self-efficacy, and engineering identity. For lower-division students, all outcomes were significantly positively correlated with leader identity (r (27) > 0.483, $p < .011$), Table 19. For upper-division, the same relationships held (r (51) > 0.370, $p < .008$), with engineering identity excepted, Table 20. Engineering relationship to leadership was also included in the table for reference, as it directly connects leadership and professional identities.

4.4. Hypotheses 4L/4U

H4L$_a$: Change in engineering leadership construct correlates with change in leader identity of lower-division students.

H4U$_a$: Change in engineering leadership construct correlates with change in leader identity of upper-division students.

Hypothesis 4 proposed that change in participants' leadership construct predicts change in their leader identity. Correlation and regression analyses demonstrated clear

Table 16: Stepwise regression table, leader identity, lower-division

Term	Coeff	SE Coeff	*t*-value	*p*-value
Constant	-1.28	1.72	-0.74	0.468
OTL-Power	0.396	0.254	1.56	0.136
OTL-Develop	0.085	0.334	0.25	0.802
OTL-Shared	-0.259	0.289	-0.90	0.383
Engr Ldrshp Relation	0.698	0.206	3.38	0.003
Interact w diverse	0.496	0.279	1.78	0.092

Underlined indicates significance at $\alpha = .05$

Table 17: Stepwise regression table, leader identity, upper-division

Term	Coeff	SE Coeff	*t*-value	*p*-value
Constant	4.55	1.42	3.20	0.003
OTL-Power	-0.214	0.150	-1.43	0.161
OTL-Develop	0.240	0.173	1.39	0.172
OTL-Shared	-0.270	0.217	-1.24	0.220
Engr Ldrshp Relation	0.278	0.116	2.41	0.020
Program leadership overlap	-0.293	0.152	-1.93	0.061
Interact w diverse	0.271	0.160	1.70	0.097

Underlined indicates significance at $\alpha = .05$

Table 18: ANOVA table, leader identity by major, lower-division

Source	DF	Contribution	Adj SS	Adj MS	*F*-Value	*p*-value
Ldrshp Interest	1	42.95%	8.570	8.5698	6.04	0.029
MAJOR	5	21.49%	11.148	2.2297	1.57	0.236
Error	13	35.56%	18.447	1.4190		
Lack-of-Fit	4	3.46%	1.792	0.4481	0.24	0.907
Pure Error	9	32.11%	16.655	1.8505		

Underlined indicates significance at $\alpha = .05$; **bold**, significance at $\alpha = .001$

support for this hypothesis for all participants, per Tables 21-25. As described previously, a Bonferroni correction (for family-wise error) was used for correlation tests for significance. From correlation analysis, lower-division students showed significant positive correlation between leader identity and OTL-Shared (r (24) = .532, p = .007). It

Table 19: Correlations among outcome variables, lower-division

	Ldr Identity	Engr Ldrshp Relation	Ldrshp Interest	Ldr efficacy
Engr Ldrshp Relation	0.483			
Ldrshp Interest	**0.707**	0.289		
Ldr self-efficacy	**0.585**	0.199	**0.885**	
Engr identity	**0.645**	**0.711**	0.536	0.402

Underlined indicates significance at $\alpha = .05$; **bold** indicate significance at $\alpha = .001$

Table 20: Correlations among outcome variables, upper-division

	Ldr Identity	Engr Ldrshp Relation	Ldrshp Interest	Ldr efficacy
Engr Ldrshp Relation	0.370			
Ldrshp Interest	**0.717**	0.408		
Ldr self-efficacy	**0.727**	0.220	**0.626**	
Engr identity	-0.066	0.197	-0.149	-0.048

Underlined indicates significance at $\alpha = .05$; **bold** indicate significance at $\alpha = .001$

should be noted that the engineering leadership relationship was not significant using the (notoriously conservative) Bonferroni correction (r (25) = .454, p = .023). Upper-division students reported significant correlations with leader identity for all leadership constructs ($|r$ (50, min.) $| > .470$, $p < .001$), though the OTL-Power relationship was negative.

In addition, regression models identified several significant simultaneous relationships with leader identity. Using simultaneous relationships enables insight into predictive impacts of variables, controlling for other influences. Initial regression analysis (of change between BEFORE and NOW components of retrospective self-assessments) demonstrated significant relationships between change in leadership constructs and leader identity for all participants ($p = .010$, $R^2_{adj} = .36$; $p < .001$,

Table 21: Correlations among variable changes and control variables, lower-division

	CHANGE IN VARIABLE				
	Ldr. Identity	OTL-Power	OTL-Develop	OTL-Shared	Engr Ldrshp Relation
OTL-Power: CHANGE	-0.019				
OTL-Develop: CHANGE	0.209	-0.178			
OTL-Shared: CHANGE	0.532	-0.130	0.439		
Engr Ldrshp Relation: CHANGE	0.454	-0.352	0.142	0.215	
Position not held	-0.178	0.454	0.190	0.190	-0.198
Program leadership overlap	0.467	0.027	-0.172	0.067	0.271
Leadership use in course	-0.267	0.188	-0.621	-0.519	-0.372
Interact w diverse	0.040	0.206	-0.589	-0.676	-0.106
Female	0.142	-0.195	-0.186	-0.086	-0.029

Underlined indicates significance at $\alpha = .05$; double underline, significance at $\alpha = .013$ (where applicable for Bonferroni corrections); *italics* indicates absolute pre-survey scores.

Table 22: Correlations among variable changes and control variables, upper-division

	CHANGE IN VARIABLE				
	Ldr. Identity	OTL-Power	OTL-Develop	OTL-Shared	Engr Ldrshp Relation
OTL-Power: CHANGE	**-0.483**				
OTL-Develop: CHANGE	**0.565**	**-0.611**			
OTL-Shared: CHANGE	**0.471**	**-0.547**	**0.482**		
Engr Ldrshp Relation: CHANGE	**0.565**	-0.332	0.332	**0.535**	
Position not held	0.055	-0.166	0.262	-0.084	-0.049
Program leadership overlap	0.373	-0.214	0.151	0.337	0.310
Leadership use in course	0.117	-0.025	0.261	0.155	0.047
Interact w diverse	-0.155	-0.139	0.150	-0.009	-0.187
Female	-0.030	-0.099	-0.077	0.020	0.065

Underlined indicates significance at $\alpha = .05$; double underline, significance at $\alpha = .013$ (where applicable for Bonferroni corrections); **bold**, significance at $\alpha = .001$; *italics* indicates absolute PRE scores.

Table 23: Initial regression table, leader identity change, lower-division

Term	Coeff	SE Coeff	*t*-value	*p*-value
Constant	0.059	0.125	0.48	0.639
OTL-Power: CHANGE	-0.033	0.086	-0.38	0.709
OTL-Develop: CHANGE	-0.032	0.129	-0.25	0.806
OTL-Shared: CHANGE	0.132	0.057	2.31	0.034
Engr Ldrshp Relation: CHANGE	0.133	0.059	2.25	0.038

Underlined indicates significance at $\alpha = .05$

$R^2_{adj} = .44$; Tables 23 and 24, respectively addressing alternative hypotheses). It should be noted that two outliers (exceptionally high increase in LSI) and one leverage point were removed, as they disproportionally affected the variance (P. Cohen et al., 2014, pp. 415-417): the full data set had a negative bias that was actually stronger than the combined effect of the high scoring outliers.

Table 24: Initial regression table, leader identity change, upper-division

Term	Coeff	SE Coeff	*t*-value	*p*-value
Constant	0.007	0.118	0.06	0.951
OTL-Power: CHANGE	-0.092	0.125	-0.73	0.467
OTL-Develop: CHANGE	0.348	0.139	2.51	0.016
OTL-Shared: CHANGE	0.033	0.125	0.27	0.792
Engr Ldrshp Relation: CHANGE	0.256	0.085	3.02	0.004

Underlined indicates significance at $\alpha = .05$

A subsequent inclusive stepwise regression approach selectively explored the influence of control variables on change in leader identity, with a significant model emerging for lower-division students, with the inclusion of positional (in)experience ($p = .001$, $R^2_{adj} = .69$). The process paralleled that of the stepwise approach used to explore the absolute leader identity indicator but differed slightly due to the interest in

change in responses rather than interest in *absolute* responses (e.g., gender was used as a control, but not change in gender). Lower-division students with semester leadership roles had the most growth in leadership (b = -.484, p = .002), per Table 25. Position was a powerful regressor, accounting for 24% of total LSI variance. No significant controls emerged for upper-division participants. A summary of the regression criteria and results may be found in Table 26.

Table 25: Stepwise regression table, leader identity change, lower-division

Term	Coeff	SE Coeff	*t*-value	*p*-value
Constant	0.843	0.226	3.73	0.002
OTL-Power: CHANGE	0.058	0.068	0.85	0.406
OTL-Develop: CHANGE	-0.206	0.107	-1.93	0.071
OTL-Shared: CHANGE	0.229	0.050	4.59	**0.001**
Engr Ldrshp Relation: CHANGE	0.133	0.044	3.02	0.008
Position not held	-0.484	0.127	-3.80	0.002

Underlined indicates significance at α = .05; **bold**, significance at α = .001; *italics* indicates absolute PRE scores.

Finally, additional relationships of changes in important outcome variables were explored (Tables 27 and 28). For lower-division students, there was no additional significant relationships with LSI that emerged. However, leadership interest, self-efficacy, and engineering identity changes were all significantly correlated with one another. Upper-division students, on the other hand, demonstrated significant relationships between almost all shown variables. Changes in leader identity were significantly correlated with changes in all three outcomes: leadership interest, self-efficacy, and engineering identity.

Table 26: Regression details, predictors of change in leader identity

Approach	Tactic	Class level	Controls	*p*-value	PRESS
Initial	Simple	Lower-division	N/A	.018	2.7
Inclusive	Stepwise	Lower-division	COURSE, POS	**<.001**	1.6
Initial	Simple	Upper-division	N/A	**<.001**	20.0
Inclusive	Stepwise	Upper-division	NONE	**<.001**	20.0

Underlined indicates significance at $\alpha = .05$; **bold**, significance at $\alpha = .001$

Table 27: Correlations among changes in outcome variables, lower-division

	CHANGE IN VARIABLE						
	Ldr. Identity	OTL-Power	OTL-Develop	OTL-Shared	Engr Ldrshp Relation	Ldrshp Interest	Ldr efficacy
Ldrshp Interest: CHANGE	0.144	-0.085	0.164	0.166	0.139		
Ldr efficacy: CHANGE	0.311	-0.164	0.050	0.394	0.148	**0.812**	
Engr identity: CHANGE	0.170	-0.381	0.173	0.213	0.374	**0.589**	0.543

Underlined indicates significance at $\alpha = .05$; **bold**, significance at $\alpha = .001$

Table 28: Correlations among changes in outcome variables, upper-division

	CHANGE IN VARIABLE						
	Ldr. Identity	OTL-Power	OTL-Develop	OTL-Shared	Engr Ldrshp Relation	Ldrshp Interest	Ldr efficacy
Ldrshp Interest: CHANGE	**0.585**	-0.391	0.347	**0.429**	**0.442**		
Ldr efficacy: CHANGE	**0.806**	**-0.505**	**0.523**	**0.524**	**0.596**	**0.613**	
Engr identity: CHANGE	**0.549**	-0.177	0.388	0.216	0.099	0.408	**0.447**

Underlined indicates significance at $\alpha = .05$; **bold**, significance at $\alpha = .001$

4.5. Hypothesis 5

$H5_o$: Reflexive instruction about engineering leadership does not influence lower-division students' leader identity differently than it influences upper-division' identity.

This hypothesis compared lower-division and upper-division change in leader identity. An ANOVA model comparing change in leader identity with class level (including relevant controls) in school was not significant (F (1, 76) = 0.70, p = .405) (Appendix V).

4.6. Hypothesis 6

$H6_o$: Reflexive instruction about engineering leadership does not influence lower-division students' engineering leadership construct differently than it influences upper-division students' construct.

This hypothesis compared lower-division and upper-division change in leadership construct. ANOVA models comparing change in engineering leadership construct with class level (including relevant controls) in school was not significant. Appendix V includes analysis details. A Bonferroni correction was used to address family-wise error, resulting in α = .013.

4.7. Qualitative

4.7.1. Research Question 1

RQ1: Does reflexive instruction about engineering leadership influence leader identity?

The qualitative data supported the quantitative findings by providing insight into how reflexive instruction influenced leader identity growth. Participants talked about the direct impact of the intervention in three core ways that addressed this hypothesis: learning the vocabulary of leadership, reflecting on previous experiences, and seeing themselves as emerging.

4.7.1.1. Learning Vocabulary. Learning the vocabulary of leadership helped students to improve their understanding of leadership and interpret their own experiences with improved clarity. As a result, their own leader identity developed. There were two ways in which student leadership understanding shifted: they either expanded their view of leadership beyond a (popular and simplistic) heroic model, or they strengthened (or clarified) their view. An example of the first came from Alfred (pseudonyms used throughout), an upper-division male:

> My [perspective] on engineering leadership has expanded. This is because I have taken on a leadership role in my group…I now see myself as a leader in small groups and am learning on how to become more comfortable being a leader in larger groups.

Table 29: Coding distribution, number of references by class level

Codes	Lower-division	Upper-division
Collaborative Optimization	40	36
Organizational Innovation	17	9
Technical Mastery	17	13
Change in engineering leadership perspective- NO	4	8
Change in engineering leadership perspective - YES	12	26
Engineering and Leadership relationship	28	23
Engineering and Self	2	3
Leader and Self - Confidence	7	6
Leader and Self - Interest	6	8
Leader and Self - NO	6	14
Leader and Self - YES	8	7
Leader and Self -Emerging	19	4
Orientation to Leadership - Power	16	41
Orientation to Leadership - Development	21	16
Orientation to Leadership -Share	13	17
Skills	101	59
Skills-People	41	16
Skills-Tech	31	15

These participants were able to see themselves more easily as leaders because their expanded view aligned with their own existing identities.

In addition, even students who did not necessarily change their view of leadership found their view strengthened. Anne, a lower-division female, provided an example of strengthened views of leadership due to the intervention: “I don't think that I have a different view of leadership…I now have a stronger and more precise perspective of leadership. Before I had a good idea but no expectations about leadership in engineering until now.” These students often reported both strengthened self-efficacy and clearer understanding of their own leadership.

4.7.1.2. Reflecting on Experience. The second direct impact of the intervention was due to the reflective nature of the essays. These helped students apply new leadership concepts in situations they knew, either as a leader or as a group member. This provided insight into common landmarks in engineering leader identity development; these landmarks add texture to the changing leader identity that participants experienced.

4.7.1.3. Leadership is Emerging. Essay responses provided insight regarding student self-identification as an engineering leader ("Would you consider yourself as-– or becoming– an emerging engineering leader? If so, in what way? If not, why not? "). Participants were somewhat evenly split between their self-identification: just under 1/3 said Yes (15/58), 1/3 said No (19/58), and just over 1/3 said Emerging (21/58). However, parsing the responses by class level revealed differences within the population. While Yes response frequency was similar across the population, lower-division students were far more likely to say No (58% vs. 25% of upper-division students). Typical of this group, Victor said, "I would not see myself as an engineering leader at this point because I have held no positions of leadership really in anything to do with engineering." In contrast to this view, upper-division students were far more likely to self-report as emerging engineering leaders (63% vs. 21% of lower-division participants):

> I would consider myself becoming an emerging engineer leader… throughout my time in [my university] I have encounter[ed] several instances where I had to step up and express the traits of [an] engineer leader. At the start of my education in [my university] there are not many leadership roles one can take.

4.7.2. Research Question 2

RQ2: Does reflexive instruction about engineering leadership influence engineering leadership construct?

The qualitative analysis both supported quantitative findings and provided additional insight into how reflexive instruction influenced students' engineering leadership construct. Informing students first about more expansive ways to view leadership, and then about authentic models of engineering leadership emerged as the most influential aspects of the intervention for engineering leadership construct.

The number of students responding that their perspective had changed clearly supported the quantitative results: students were three times more likely to report that their understanding of engineering leadership did change than did not. Moreover, when students spoke about specific ways their outlook changed, they agreed with the quantitative findings: their perception of leadership as power- and position-based lessened (OTL-Power); they detailed specific leadership skills that they could develop (OTL-Development); and they discussed the importance of everyone's influence on group success (OTL-Shared). Resonating with the increase in OTL-Develop and OTL-Shared, students frequently addressed the need for skill development, especially in terms of interpersonal skills (e.g., communication, as outlined previously) and internal development (e.g., developing trust in others).

The most substantive quantitative change in leadership construct was that of the relationship between engineering and leadership (ELR) for lower-division students ($\eta = 1.250$). This aspect of leadership construct was addressed by several reflection

essays that noted an epiphanic moment (e.g., "… [the intervention] opened my eyes to how engineering leadership can be utilized in today's society…"). That said, this relationship shifted for upper-division students as well: one upper-division female student commented that the message that engineers are supposed to be leaders is simplistically repeated in many classes. In contrast, she found the details of different forms of leadership particularly interesting and compelling, echoing the sentiments of many upper-division students.

The qualitative data also provided insight into how reflexive instruction influenced engineering leadership construct: the informative videos and class discussion provided clearer vocabulary and more authentic scaffolding of how leadership is practiced in the profession. Students reported an increased clarity (e.g., using terms such as 'relational,' 'democratic,' etc.), breadth (e.g., multiple leadership styles), and depth (e.g., how leadership is practiced in engineering) of understanding of leadership. The qualitative data suggest that the reflective features of the intervention components may have supported participant shift in perspective.

While students talked about more expansive views of leadership, a positional, top-down view of leadership pervaded responses at all class levels. When students addressed the engineering leadership definition prompt, they were much more inclined to use an OTL-Power framework than other frameworks: over 80% of the time a framework was used in exploring engineering leadership, it was power-based. Another situation in which the OTL-Power framework was regularly leveraged was in discussion of extracurricular experiences. Participants' discussions of previous experiences were used to support their

self-efficacy as leaders, their dependence on their teammates, and an appreciation for leadership effectiveness.

4.7.3. Research Question 3

RQ3: Does engineering leadership construct influence leader identity?

The mixed nature of the quantitative results for this research question was reflected by the qualitative data. Only one theme emerged that addressed a relationship between leader identity and engineering leadership construct going into the intervention. However, four themes emerged that elucidated the connection between identity and construct as a result of the intervention.

The only theme that addressed identity and construct going into the intervention was regarding an 'emerging' leader identity: when students self-identified as emerging, they were far more likely (67%) to use a development construct (i.e., OTL-Development) than either power or shared, reflecting a belief that they could learn and develop as engineering leaders. These students saw themselves on a continuum of becoming an engineer, rather than adopting a binary state of existence. Aligned with the idea of becoming is the idea of learning and adopting new ways of being. Likewise, all students who were eventually able to see leadership in shared or relational terms (i.e., OTL-Shared), were able to see themselves as engineering leaders or emerging engineering leaders.

On the other hand, the qualitative data provided extensive insight into the impact of reflexive instruction: in other words, how change in engineering leadership construct

impacted change in leader identity, as a result of reflexive instruction. Three prominent ideas emerged in the qualitative data. Moreover, one contrary case highlighted the non-linearity and complexity of identity development.

First, students widely wrote about the impact of the intervention on changing their outlook on engineering leadership. More importantly, they also addressed ways in which this perspective personally affected them. For some it provided a model for working more effectively in groups towards a common goal:

> What I learned that really shifted [my] view was the laissez faire and democratic styles of engineering leadership existing, where leadership feels almost like not quite the right term for it. You're just collaborating amongst each other, each taking charge as need be, all tossing ideas out, working as a big unit without a single person necessarily designated as a leader.

Second, an expanded view of leadership was an especially powerful influence on identity development. For example, one upper-division female student said, "This new perspective has also given me the wherewithal to try to strengthen my own engineering leadership." And another participant said the following:

> I learned a lot from these lessons on engineering leadership. I was not aware that there were different kinds of leadership that impacts the workforce in different ways. With this newfound knowledge I feel like I can be leader in my own right in the future.

Third, participants also found the three engineering leadership orientations useful as a scaffolding tool as they considered their own development. The reflection exercises and group-based discussions provided empowering contexts for effecting this growth. As a result, they more readily could perceive themselves in an engineering leadership context. For example, Eugene, a lower-division male participant, said the following:

> These three types opened my eyes to the different types of leadership, and what might best suit myself. Knowing that there are different types makes engineering leadership more interesting and seems less like a one size fits all attitude.

Many reported that the Collaborative Optimization engineering leadership orientation was a model that was personally compelling: 58% of discussion of the three engineering leadership orientations was about collaborative optimization. This model allowed them to see the value of communicating effectively and of everyone contributing to group success. For instance, Adeline said the following:

> I see myself becoming an engineering leader with a focus in collaborative optimization. I am a people person. I pride myself in my ability to connect and talk to almost anyone. I have always had a wide variety of interests and over time I have become very competent in many of those interests.

Finally, one contrary case emerged as a participant reported an actual decrease in leadership self-identity due to the intervention. While technically not an outlier, she reported a marked negative shift in LSI from the intervention, and her post-intervention essay reflected this shift. This female senior student, Madeline, found that her understanding of leadership was challenged by the intervention. With increased reflection on engineering leadership traits, she developed more rigorous standards for an engineering leader (mainly around motivation and inspiration). As a result, her confidence in her own ability to identify as a leader was shaken. As a result of these elevated expectations, her own status as a leader—based on competence and responsibility—fell into question: “How can I hope to be a leader if I can’t identify one in my peers or colleagues?” This led to confusion about engineering leadership and a corresponding strong decreased leader identity.

4.7.4. Research Question 4

RQ4: Does reflexive instruction about engineering leadership influence lower-division students' leader identity differently than it influences upper-division students' identity?

The only differences that emerged based on class year have been discussed in their corresponding sections (e.g., interest, regression relationships by class year, and how leader identity changes were perceived). While student class year was important to student leader identity change in some ways, shifts in leadership construct were the primary influencer of this change. In other words, differences (by class level) in engineering leadership construct change seemed to be the mediating predictor of any differences (by class level) in leader identity change.

4.7.5. Research Question 5

RQ5: Does reflexive instruction about engineering leadership influence lower-division students' engineering leadership construct differently than it influences upper-division students' construct?

The qualitative data provided some additional insight into the ways construct changes depended on class level in school. For a start, lower-division students were twice as likely to indicate that their perspective on engineering leadership changed (as upper-division students). Moreover, the nature of the change reported was different between class levels, as reported earlier. For lower-division participants, the change was often superlative, and it seemed to impact their outlook in powerful ways. They used

terms like 'changed a lot' or 'definitely changed'. On the other hand, for upper-division participants, the change was subtler. They used terms like 'expanded' or 'shifted'.

In addition, lower-division students reported that insights into different leadership perspectives seemed to open ways of seeing and experiencing leadership. This was especially influential as they differentiated leadership in the profession from the way it functions in broader society. Upper-division students reported that the intervention gave them a more expansive and clearer way of integrating the experiences they've had and the particular skills they've developed.

Another distinction between how these groups were affected by the intervention pertained to those who did not report a shift in leadership views. Lower-division individuals indicated that while their opinion may not have changed, they did gain precision (or strength) on what they believed. Upper-division individuals were a little firmer, indicating their extensive experience in leadership situations had prepared them adequately.

4.8. Power Analysis

Post hoc power analysis identified power achieved for all hypotheses, per Table 30 ($\alpha = 0.05$ unless noted otherwise). GPower (v 3.1.9.6) was used for all calculations. For H1 and H2 (t-tests on difference between BEFORE and NOW), the achieved power was above .814 for all tests. For H3 and H4, both correlation and overall regression results are listed. Finally, for H5 and H6, ANOVA achieved power is shown. For significant results, the median power achieved was .901. Eight tests that were significant, but fell below an 80% power threshold, are summarized in Table 31 ($\beta > .20$).

4.9. Summary

In summary, the data fully supported hypotheses 1, 2, and 4: the intervention effected change in leader identity and engineering leadership construct; moreover, change in construct predicted change in identity. There was limited support for hypothesis 3, with engineering leadership relationship being the only significant construct. While support for hypotheses 5 and 6 was weak, the qualitative data provided some insight into

Table 30: Power analysis final results (based on $\alpha = 0.05$, except where noted).

Hypothesis: Analysis approach	Effect size observed	Sample size	Power achieved
H1L: t-test, Lower-division	.859	27	.990
H1U: t-test, Upper-division	.642	51	.994
H2L: t-test, Power, Lower-division	-.691	27	.814
H2U: t-test, Power, Upper-division	-.685	55	.993
H2L: t-test, Development, Lower-division	.751	26	.866
H2U: t-test, Development, Upper-division	.581	54	.952
H2L: t-test, Shared, Lower-division	.956	27	.985
H2U: t-test, Shared, Upper-division	.977	55	.999
H2L: t-test, ELR, Lower-division	1.25	28	.999
H2U: t-test, ELR, Upper-division	.789	54	.999
H3L: Correlation, Power, Lower-division	.208	20	.054
H3U: Correlation, Power, Upper-division	-.213	46	.145
H3L: Correlation, Development, Lower-division	.221	20	.060
H3U: Correlation, Development, Upper-division	.118	46	.045
H3L: Correlation, Shared, Lower-division	.202	20	.051
H3U: Correlation, Shared, Upper-division	.071	46	.023
H3L: Correlation, ELR, Lower-division	.483	20	**.410**
H3U: Correlation, ELR, Upper-division	.370	46	**.549**
H3L: Multiple regression, Lower-division	.408	27	.659
H3U: Multiple regression, Upper-division	.235	51	**.753**
H3L: Stepwise regression, Lower-division	.449	11	**.162**
H3U: Stepwise regression, Upper-division	.333	46	**.781**
H4L: Correlation, Power, Lower-division	-.019	24	.013
H4U: Correlation, Power, Upper-division	-.483	50	.901
H4L: Correlation, Development, Lower-division	.209	24	.066
H4U: Correlation, Development, Upper-division	.565	50	.986
H4L: Correlation, Shared, Lower-division	.532	24	**.647**
H4U: Correlation, Shared, Upper-division	.471	50	.879
H4L: Correlation, ELR, Lower-division	.454	24	**.436**
H4U: Correlation, ELR, Upper-division	.565	50	.986
H4L: Multiple regression, Lower-division	.563	27	.812
H4U: Multiple regression, Upper-division	.788	51	.999
H4L: Stepwise regression, Lower-division	2.226	11	**.633**
H4U: Stepwise regression, Upper-division	.788	51	.999
H5: ANOVA	.069	78	.093
H6: ANOVA, Power	.019	82	.014
H6: ANOVA, Development	.039	81	.018
H6: ANOVA, Shared	.199	82	.236
H6: ANOVA, ELR	.284	82	.514

Underlined indicates significance at $\alpha = .05$; double underline, significance at $\alpha = .013$ (where applicable); **bold,** $\beta > .20$, $p < \alpha$; *italics* indicate Bonferroni correction, $\alpha = 0.013$

Table 31: Significant tests with low power (based on $\alpha = 0.05$ and $\beta = 0.20$, except where noted).

Hypothesis: Analysis approach	Effect size observed	Sample size	Power achieved
H3L: Correlation, ELR, Lower-division	.483	20	.410
H3U: Correlation, ELR, Upper-division	.370	46	.549
H3U: Multiple regression, Upper-division	.235	51	.753
H3L: Stepwise regression, Lower-division	.449	11	.162
H3U: Stepwise regression, Upper-division	.333	46	.781
H4L: Correlation, Shared, Lower-division	.532	24	.647
H4L: Correlation, ELR, Lower-division	.454	24	.436
H4L: Stepwise regression, Lower-division	2.226	11	.633
H6: ANOVA, ELR	.284	82	.514

italics indicate Bonferroni correction, $\alpha = 0.013$

the respective research question. Generally, the quantitative and qualitative data aligned in answering the research questions.

CHAPTER FIVE

DISCUSSION

Using an identity lens, this study has explored the impact of reflexive instruction on leader identity, thereby accomplishing the research purpose. The results were clear that reflexive instruction impacted student leader identity and engineering leadership construct. Moreover, the ways in which the construct predicted identity provided insight into how to cultivate leader identity. Exploring the engineering leadership construct and other student characteristics (e.g., interest and qualitative themes) has provided additional insight into the ways in which this instructional intervention impacted identity. The research questions and main findings of this study are summarized in Table 32.

This chapter outlines the impact of these findings on both our understanding of engineering leadership development and our ability to cultivate it through engineering education. The structure will proceed as follows. First, how the findings have addressed gaps in the literature will be discussed. Second, implications and limitations of the research will be presented. Finally, directions for future research and brief conclusions will complete this dissertation.

5.1. Reflexive Instruction Impact

The quantitative results indicated that reflexive instruction had a significant impact on every measured outcome (e.g., leader identity, leadership interest, leadership self-efficacy). Moreover, the impacts were characterized by large effect sizes. For perspective, the Hattie Index assesses the relative importance and impact of educational

interventions, finding a mean effect size of 0.4. This approach suggests that many interventions impact students; researchers and practitioners should focus on those that have the biggest impact: interventions with effect sizes above 0.4 are worth pursuing. Moreover, effect sizes above 0.6 are large and offer meaningful improvement to student development (Hattie, 2015). This is especially remarkable considering upper-division students have already had at least three years of college experience to develop, with some of that experience was sure to be working with peers on a technical

Table 32: Research questions and main findings

Reference	Question	Main Findings
RQ1	Does reflexive instruction about engineering leadership influence leader identity?	Reflexive instruction increases leader identity.
RQ2	Does reflexive instruction about engineering leadership influence engineering leadership construct?	Reflexive instruction decreases power orientation; it increases all other components of the engineering leadership construct: leadership development, leadership sharing, and relationship between engineering and leadership.
RQ3	Does engineering leadership construct influence leader identity?	Engineering leadership relationship positively predicts leader identity.
RQ4	Does reflexive instruction about engineering leadership influence lower-division students' leader identity differently than it influences upper-division students' identity?	No significant differences.
RQ5	Does reflexive instruction about engineering leadership influence lower-division students' engineering leadership construct differently than it influences upper-division students' construct?	No significant differences.

project, paralleling the type of work engineering professionals enjoy. While these results do appear promising, they are far from conclusive given validity concerns inherent in naturalistic studies. Nonetheless, these results suggest that engineering students at all levels are well-positioned to improve multiple leadership-based outcomes with reflexive instruction. The impact of reflexive instruction can be summarized in three categories: leader identity, engineering leadership construct, and other outcomes.

5.1.1. Leader Identity

The first category of reflexive instruction impact pertains to leader identity. Students reported significant increases in leader identity (t (27) = 4.46, $p < .001$; t (51) = 4.58, $p < .001$; lower-division and upper-division, respectively). The nature of the study prohibited complex quantitative modeling (e.g., structural equation modeling) of how components of the intervention caused or mediated this change. However, the findings did provide some insight into the reasons students reported significant growth (on average) in leader identity after this intervention. Discussion of the impact of engineering leadership construct on leader identity is conducted separately.

While the quantitative data showed significant increase in leader identity from before to after the intervention, further qualitative analysis suggested two important ways students were affected: providing students with leadership vocabulary and with an opportunity to reflect on their personal experiences. The short videos of various leadership styles empowered students to think critically about leadership using appropriate vocabulary. This empowered some students to expand their understanding and others to strengthen their beliefs. For both types of students, the opportunity to

reflect on and discuss their personal perspectives and preferences enabled them to shift their view of themselves as leaders. The use of reflection was critical in cultivating shifts in belief, and group contexts supported that reflection effectively.

One component of the intervention that seemed to impact many participants was introducing the idea of *emerging* as a self-designation of engineering leadership. This idea was used in the outlook essay prompt: "Would you consider yourself as-– or becoming– an emerging engineering leader?" The effect on student self-assessment was noticeable in the qualitative data, especially for upper-division students. The qualifying nature of *emerging* seemed to empower students to self-designate as engineering leaders. Moreover, the qualitative data indicated that *emerging* was used to express a developmental view of leadership.

The identity literature provides further explanations for why using a process-based framework (i.e., emerging) is useful for understanding identity growth. For example, this shift in thinking may reflect the increased self-efficacy that students feel as they practice increasingly complex tasks as part of their training. If so, it would indicate that institutional experiences that provide students the opportunity to authentically engage are making a difference. *Emerging* also implies the process of becoming, an essential component of learning according to the COP model. The COP model suggests that emergent views allow for a transitional space, providing some of the same advantages that legitimate peripheral participants enjoy (Lave & Wenger, 1991). It also allows for curiosity, failure, exploration, and beginner-behavior, all of which are also important in professional growth within the provisional self model (Ibarra, 1999). The Performance /

Competence / Interest / Recognition (PCIR) construct implies that engineering identity increases as recognition of increasingly complex capabilities occurs (Hazari et al., 2010). Finally, the peculiar nature of engineering vocabulary, whereby the precise boundary of designation as an engineer is unclear (as opposed to other autonomous professionals like doctors, lawyers, and accountant), introduces uncertainty into how students see themselves. The use of the word emerging addresses this difficulty, while conveying a sense of belonging with the profession. However, conclusively stating that any of these processes drove student response is well beyond the scope of this study.

One valuable and promising quantitative relationship did emerge during this study that helps to understand leader identity, especially amongst upper-division students. The impact of the intervention on leader identity seemed to be especially powerful for those who had lower leadership interest and leader self-efficacy (r (51) = -.641, $p < .001$; r (51) = -.621, $p < .001$; respectively). A possible explanation for this findings is that these students might be found in Tonso's (2006) nerd category of engineers, who are reluctant to self-identify as leaders. Rather, they are more interested in technical competence over public recognition. Providing these students with a model that contextualizes leadership as working together towards a common goal-- or bearing technical responsibility-- was especially compelling. Moreover, showing these students various ways in which leadership is practiced in the profession made it easier to imagine themselves as engineering leaders, promoting a sense of belonging. The group work component of the intervention also provided a venue through which these 'introverted' engineering students could connect with others that had similar outlooks, providing peer support. This shift is

important, as these students typically demonstrate superior technical acumen (Tonso, 2014), so their contribution to projects is particularly important. Finally, regardless of the cause of this finding, it is important because it demonstrates that reflexive instruction may be especially valuable for those students least likely to pursue leader development in college. In other words, this intervention didn't just preach to the choir; rather, it empowered students (at least upper-division) who are typically disenfranchised by leadership as they have experienced it in college.

5.1.2. Engineering Leadership Construct

This category addresses the engineering leadership construct factors. The quantitative data found that change in understanding of the relationship between engineering and leadership (ELR) was significant due to reflexive instruction (t (28) = 6.61, $p < .001$; t (54) = 5.80, $p < .001$; lower-division and upper-division, respectively). Moreover, the qualitative data suggest that operationalizing engineering leadership was one of the most impactful influences on increased engineering leadership relationship. By introducing and exploring the three orientations of engineering leadership (Technical Competency, Collaborative Optimization, and Organizational Innovation), students were able to understand realities of the engineering profession with increased detail (Rottmann et al., 2015). Of course, teaching students the vocabulary of these models and supporting group discussion about them were important aspects of exploring these orientations of engineering leadership.

The Collaborative Optimization (and Technical Competence to a lesser extent) orientation was especially meaningful to participants. Both orientations are mirrored in

typical engineering education environments, through cross-discipline group work and individual problem-solving, respectively. The most noticeable impact of the Collaborative Optimization model was presenting students with a description of leadership that included informed collaboration rather than a charisma. This understanding of leadership echoed relational approaches to leadership and was widely embraced by many participants. Specifically, leadership through collaboration resonated with their perception that engineering leadership could be rational and grounded in science, rather than emotion or charisma.

The Collaborative Optimization model also promoted a developmental view of leadership and a shared view of leadership (OTL-Development and OTL-Shared, respectively). Participants reported significant and substantial increases in both orientations. Moreover, significant correlations existed between Development and Shared leadership orientation growth for all students (R (20) = .439, $p < .05$; R (46) = .482, $p < .001$; for lower-division and upper-division, respectively), reflecting the alignment between being able to learn leadership skills and the value for all members to participate in group direction. The qualitative data indicated that this growth was cultivated in several ways.

First, through reflection and group discussion, participants were able to see ways in which they were already exercising this model, even if in limited capacity. While the traditional engineering education classroom model is notoriously hierarchal, there are still programmatic components that are more authentic (e.g., capstone courses or course group projects). As a result, Collaborative Optimization also resonated with the experiences

students had in group projects, where various people contributed in differing ways to the success of the group. In fact, the very structure of effective classroom group projects assumes that each member of a group bears responsibility for some aspect of the work and can influence group direction, facilitating a shared view of leadership. Because of their experience, they were able to see ways in which they engaged effectively (and ineffectively) in groups. Moreover, they were able to identify specific collaborative leadership skills that they wanted to develop, especially amongst the upper-division population.

As students learned about the complex, various ways in which leadership may be practiced, the many skillsets required to work with other people emerged as a topic of conversation. These conversations (and the SMART goal assignment, for upper-division students) highlighted the developmental aspect of these skills. In other words, as students talked about various skillsets (such as conflict resolution or communication), relevant experiences (both first- and second-hand), personal goals, and the dynamic nature of skill development became clearer. Instead of seeing leadership solely as a function of charismatic personality (which you either have or you don't), students saw it as a meaningful professional skill. And, just like engineering technical skills, this professional skill can be developed.

Providing leadership models that align with typical student experience enabled participants to interpret previous classroom experiences in more complex terms, while also appreciating the ways in which their experiences are similar to those of professional engineers. Furthermore, group discussion normalized leadership as a process that is

necessary for accomplishing group objectives, rather than a characteristic of dynamic personalities. In sum, exploring the similarities between leadership in the profession and leadership in engineering coursework allowed students to think more complexly and personally about engineering leadership.

The final aspect of the engineering leadership construct was a decreased belief in a power-oriented leadership framework, the only factor to decrease (t (27) = -3.59, p = .001; t (55) = -5.08, $p < .001$; lower-division and upper-division, respectively). Decrease in this orientation reflects students taking a more expansive view of leadership, as they realize that power-based coercion is not the sole way in which leadership is practiced. Group work and class-wide discussion during the intervention was important, due to two effects. First, students shared supportive and destructive behaviors from various leaders, managers, and superiors in their experience. Second, students were able to integrate leadership style vocabulary into this discussion (e.g., democratic and autocratic styles) that they had learned through pre-lecture videos. Through class discussion, expansive ways of thinking about and applying leadership styles were scaffolded. Nonetheless, students continued to use the vocabulary of a power-oriented framework when defining engineering leadership, describing previous leadership experience, and even discussing relational leadership. This reflects the complex non-linear characteristic of identity growth, where transitions involve periods of progress and regress (e.g., Ibarra, 1999; Kegan, 1982); it also agrees with findings from the LID model for students in the differentiation process (Komives et al., 2006).

5.1.3. Other Outcomes

The fourth category of reflexive instruction impact relates to other outcomes: leadership interest, leadership self-efficacy, and engineering identity. These outcomes provided insight into important ways that students were impacted by the intervention that indirectly relate to identity. The first outcome is leadership interest, which increased significantly for lower- and upper-division students (t (27) = 4.91, $p < .001$; t (54) = 4.72, $p < .001$; respectively). By providing more expansive ways of viewing leadership, students found it easier to align their personal values and interests with one (or in some cases more than one) leadership approach that they had not yet considered (such as relational approaches). As a result, not only could they more easily see themselves as leaders, but they were interested in developing this characteristic.

The literature further supports the value of this finding. Given the central role interest plays in subjective task value (STV), this promising finding indicates that the intervention supports student motivation to develop leadership (Eccles et al., 1983; Komives et al., 2005, p. 602; Matusovich et al., 2010). In addition, by focusing on the positive value of leadership for success in the engineering profession, the utility aspect of STV is leveraged to improve motivation. Finally, increased interest is an essential component of engineering identity, according to the PCIR model (Carlone & Johnson, 2007).

Not only did students report an increased interest in leadership, but they also reported increased self-efficacy in developing themselves (medium-large effect sizes, $\eta = .71$; $\eta = .63$; for lower-division and upper-division respectively). The mechanisms

for increased self-efficacy were overall like those of increased interest, which is unsurprising given the strong correlation between the two. Expansive leadership models enabled students to see that many competencies contribute to effective leadership, such as technical acumen, creativity, project management, and communication. More, students appreciated that these competencies can be developed. In addition, students were more likely to see themselves as developing leaders when they had more models from which to draw—one of which inevitably aligned with their own values and self-view. Finally, providing students with the opportunity to reflect on their previous experiences gave them an opportunity to see the importance of these competencies, and that developing them makes a difference to the success of the team.

The literature supports the value of leadership self-efficacy, as well. If interest leverages the value of expectancy-value theory, this outcome leverages expectancy, further cultivating motivation to develop leadership. The importance of self-efficacy is central to leader identity (via the Developing Self source), professional identity (as the handle of the competence pitchfork), and self-authorship (as one of one of the four pillars) (Baxter Magolda, 1998; Klemp, 1977; Komives et al., 2005). Here, giving students expansive models of leadership in the profession not only increased leader identity and interest, but confidence in their ability to develop as leaders.

Unexpectedly, participants reported a significant increase in engineering identity. While the mechanisms for this change are not clear, the data indicates two likely reasons for this growth. First, by highlighting the emergent characteristic of engineering leadership (through the essay prompt suggesting emerging as an option for engineering

leadership), students may have been more likely to abandon positional views of leadership and engineering alike. The positive relationship between change in leadership and engineering identities (r (51) = 0.549, $p < .001$) indicates that upper-division participant growth between these two is strongly related. From this perspective, seeing the complexity of the profession (in terms of leadership) may have made it easier for students to appreciate a more nuanced view of being an engineer. Also supporting this view is the relationship between a changed developmental view of leadership and growth in engineering identity (r (54) = 0.388, $p = .004$): participants who increased their belief that leadership could be developed were more likely to see themselves as engineers.

A second possible explanation for the increase in engineering identity is that a more detailed and authentic exploration of the engineering profession (in terms of leadership) enabled students to see more breadth in the profession. This breadth enabled them to imagine themselves as engineers and to see aspects of engineering that aligned with their own existing values. In other words, students were able to think about engineering in more expansive terms, possibly by being shown the many ways that engineers practice leadership. For example, the introduction of interpersonal skills into the professional domain may have enabled students to see their position as an engineer as emergent, since these skills can be developed. This interpretation is supported by aspects of lower-division student responses. For example, engineering leadership relationship (ELR) was positively correlated with engineering identity, possibly suggesting that students who think more expansively about the complexities of being an engineer were better able to see themselves as one. The group component of the intervention also

provided students an opportunity to talk about how they envisioned themselves as engineering leaders. This also has the benefit of providing opportunity to reflect carefully on what being an engineer might look like, as well as hearing about the multiple ways in which their peers imagine their future professional selves.

While both explanations are reasonable, they are far from conclusive. More research on engineering identity growth may illuminate the causal mechanisms at play in this study. That said, if a causal connection does exist between engineering and leader identities, it may indicate that leadership development is more than just another professional skill to be learned; it may mean that leadership development is instrumental in the socialization of engineering students to the profession. Regardless, the substantial impact of reflexive instruction on engineering identity growth is promising as a component of engineering education overall, not just engineering leadership development. Moreover, students are positively influenced when they can see themselves as on a professional journey. This phenomenon may provide insight into developing pedagogical approaches that leverage the emergent characteristic of the engineering profession.

5.1.4. Reflexive Instruction Summary

The impact of reflexive instruction makes several contributions to our understanding of engineering leadership development, in terms of leader identity, engineering leadership construct, and other outcomes. First, the intervention impact on leader identity demonstrated two features of leader identity that add to our understanding of it. One feature is that a short-term intervention can make a pronounced impact on

leader identity. While the engineering leadership literature suggests many practices that cultivate leader identity, no quantitative data has demonstrated the impact of a short-term intervention. For example, the existing LID model offers a description of how students develop relational approaches to leadership, as well as a plethora of classroom approaches to support this process. And there are certainly examples how course-long approaches have impacted leader identity (e.g., E. C. Johnson et al., 2015; Nino, 2016). However, this research quantitatively demonstrated the substantive impact of an identity-based intervention on student leader identity. In other words, this finding suggests that low-hanging fruit exists in leader identity development and that engineering students are poised to develop identity under the right conditions. Moreover, this research provided a concrete way that this development might be accomplished. This is especially valuable, as the reflexive instruction approach, as operationalized here, can be relatively easily scaled for large groups.

Another feature of reflexive instruction impact on leader identity is that older students who are least interested and confident in leadership are the most impacted by reflexive instruction. While the mechanisms at work here are uncertain, this finding quantitatively showed that there exists at least one instructional approach that works for those not interested in this professional competence. This finding is especially relevant to those educators interested in cultivating development of professional competencies for all engineering students.

Second, reflexive instruction impacted student engineering leadership construct. Specifically, this research quantitatively demonstrated that operationalizing engineering

leadership expanded student understanding of leadership. Agreeing with previous research on the three orientations of engineering leadership, collaborative optimization was the most widely discussed engineering leadership orientation (Rottmann et al., 2015). Student belief in Drath's (2001) leadership orientations shifted to align with actual professional practices: power-orientation decreased, shared-orientation increased, and developmental view of leadership increased. Most importantly, operationalizing engineering leadership increased student perception of the relationship between engineering and leadership. This relationship was essential in understanding leader identity growth.

Third, the positive outcomes of reflexive instruction are not limited to identity: a short-term intervention can make a pronounced impact on leadership interest and self-efficacy, as well. This finding demonstrates that increased leader identity, interest, and self-efficacy are correlated. This quantitative finding establishes a concrete relationship between identity and other important engineering leadership development outcomes. Moreover, it supports the mounting evidence that leader identity is important for continued engineering student leadership development (e.g., Rottmann et al., 2015; Schell & Hughes, 2017a; Schell, Hughes, & Tallman, 2020).

Another outcome of reflexive instruction is increase in engineering identity. More importantly, this research showed that growth in engineering and leadership identities correlate. Specifically, when students are provided with authentic models of engineering leadership, and they are provided the tools necessary to reflect on them personally, their engineering and leader identities grow together. This finding has

important implications for theory, as it suggests a connection between one's perception of oneself as an engineer and as a leader. While this finding agrees with the COP literature, the specificity of the relationship between engineering and leadership may provide insight into effective ways to prepare engineering students for the profession.

5.2. Engineering Leadership Construct Impacts Leader Identity

One factor of engineering leadership construct emerged as particularly influential on leader identity: relationship between engineering and leadership (ELR). In fact, this relationship was consistently one of the most—if not the most-- powerful influences on leader identity (and other important outcomes) that emerged in this study. In fact, every single correlation and regression analysis that compared construct with identity found that a significant relationship existed for ELR. Hence, understanding the connection between leader identity and ELR provides valuable insight into engineering leadership development. Three important aspects of this connection emerged in this study.

First, by explicitly outlining the ways in which interpersonal skills function in the profession, students could take a more expansive view of these skills. For example, authentic exploration of communication demonstrated its utility in cross-functional teams. Moreover, use of communication in this way resonated with student experiences in college, providing a framework that aligned with their experience. As a result, they were better positioned to appreciate various interpersonal skills and even perceive ways in which they were able to use them effectively. Chickering and Reisser's (1993) pitchfork analogy (also Klemp, 1977) suggests this is important to professional identity.

The second aspect of the relationship between ELR and leader identity that emerged related to students' sense of belonging with the profession. With a more expansive view of leadership, students were empowered to imagine themselves as future engineering leaders. By reflectively considering how they might serve as engineering leaders and by discussing these insights with peers, participants were able to leverage their own unique values and experiences to create a vision of their future engineering self. Moreover, participants were better able to align their own values with one of the leadership orientations. Rather than being limited by a heroic, charismatic model of leadership, students were able to appreciate other models of leadership with differing values. This led to alignment between their own values and those of the profession, as well as imagination of their own paths as engineers, both of which cultivate a sense of belonging to the profession (Lave & Wenger, 1991). Using reflection and group work empowered students to imagine their own path as engineers, which is a way of professional belonging according to the COP model (Lave & Wenger, 1991). Finally, these insights align with the quantitative findings that connect engineering and leader identities.

Third, seeing the connection between leadership and engineering impacted students' personal identity, as well. By providing models of shared leadership, the importance of all group members bearing responsibility was highlighted. By inference, if you are a group member, your input matters. It also means that your value for technical expertise is meaningful for group success. The literature supports these findings. For

example, both perspectives (your input is valued, and it is essential for success) are important to the development of self-authorship (Baxter Magolda, 1998).

In addition, analysis of the impact of the intervention found two additional relationships: for lower-division students, increased shared orientation led to increased leader identity; for upper-division students, increased development orientation led to increased identity. For lower-division students, they reimagined leadership as a process not tied to a position. Hence, students were empowered to see the importance of their own input on group decisions (e.g., "…not to be timid of voicing your own opinion/idea."). Moreover, it allowed students to see the value of everyone's input in complex projects (e.g., "…each taking charge as need be…,"). This value leads to a changing view of oneself in the LID model: one can bear responsibility and meaningfully influence the group. Because students had personal group experiences, providing scaffolding for imagining leadership as a process was effective, as students could make sense of previous experiences (Komives et al., 2005). In a reflective group context, this became especially important, as students shared their shifting views and heard from others with similar and diverse experiences. Additionally, students were more clearly able to see how interdependence was essential to group success, given the multiple areas of expertise needed for a complex project to succeed. Finally, a relational leadership model highlights the autonomous nature of the profession. In other words, everyone has the responsibility to influence project decisions related to individual technical expertise. Importantly, this responsibility rests on an individual acting independently, not on a superior dictating tasks to be accomplished.

For upper-division students, those who were able to appreciate a developmental view of leadership increased their sense of being a leader. This finding may supplement the earlier finding that connected low leadership interest with increased identity. If a nerd outlook is truly the cause of disinterest in leadership, a shift in the narrative of what a leader is may ignite interest. This interpretation would explain why an increased developmental view of leadership leads to increased leader identity. If leadership is not a personality characteristic (especially one that is not desired), but a multi-faceted skill to be developed, it is easier to perceive as learnable and dynamic. Moreover, if leadership can be seen as an important aspect of engineering success, nerds are likely to find ways to cultivate it.

Finally, the quantitative data provided limited support for the hypothesis that students' leader identity was a function of their engineering leadership construct going into the intervention. The lack of connection between leadership construct and identity in absolute terms (besides ELR) is somewhat expected, as identity is a complex construct with a multitude of influences, especially during childhood and young adulthood (but still disappointing). While an individual's leadership construct may be intrinsically connected to leader identity, quantifying this relationship may be difficult, given the many types of experiences that can be instrumental in leader identity growth. Moreover, the dynamic characteristic of development, especially during this stage of life, adds additional difficulty to understanding leadership: this may be one reason why so many leadership development models exist.

The complex relationship between engineering leadership construct and leader identity also has emerged in a number of ways through the qualitative data, not least in the negative case of Margaret. Her experience illustrated the complex and dynamic characteristics of development: in particular, development is not linear. After learning more complex vocabulary and leadership frameworks, combined with personal reflection, Margaret's crisis of confidence pervaded her entire leader identity, rather than simply her cognition about certain models. As a result, her confidence in her own leadership faltered. The literature suggests that identity transitions can be difficult, as existing cognitive frameworks fall to challenges, leaving individuals without a framework to navigate their surroundings. For example, Kegan's (1982) evolutionary truces outline the difficulties (and opportunities) of this type of personal growth. While this type of experience is typical of identity stage shifts, it is important to appreciate the precarious nature of development for the individual student. This identity characteristic highlights the need for continuing discussion of leadership (and other important professional skills), rather than a one-time class module.

In summary, connecting leadership and engineering influenced identity in multiple complex ways. This characteristic is reflected in the many aspects of professional and personal identity that were affected by the relationship between leadership and engineering. In addition, the intervention components of reflection, vocabulary, values, and group work facilitated development of multiple aspects of identity: these were especially impactful while exploring authentic models of engineering leadership. As a result, leader identity grew as participants perceived how important

leadership is within the engineering profession. While this connection was central to Rottmann et al.'s (2015) grounded theory, these results empirically demonstrate that this influence exists; and the results further illuminate characteristics of that influence.

5.2.1. Engineering Leadership Construct Summary

The engineering leadership identity literature has suggested several ways to impact the leader identity of engineering students (e.g., Nino, 2016; Racine, 2015; Rosch & Imoukhuede, 2016). However, no quantitative studies have yet demonstrated a causal mechanism for leader identity growth. This research has quantitatively demonstrated that leader identity (LSI) can be increased by increasing the perceived relationship between engineering and leadership (ELR). This finding validates the hypothesis that a compound professional leader identity is instrumental in engineering leadership development (e.g., Rottmann et al., 2015). More, it shows that ELR is the dominant concept that needs to be addressed to cultivate leader identity. This finding, along with the demonstrated impact of reflexive instruction on ELR, provides a template for substantively improving leader identity amongst engineering students.

In addition, the findings provide insight into focal areas of instruction that differ by class level. While identity theory is rich with descriptions of how students develop identity, this research has identified specific perspectives that are crucial to leader identity development, based on class level. Lower-division students may benefit most from focusing on the relational aspect of collaborative optimization. Upper-division students may benefit most from focusing on the emergent aspect of interpersonal skills used in collaborative optimization.

5.3. Class Level Influence

While the complexity of identity obscured correlations and causal relationships, several ways in which identity growth differed for different participants did emerge. First, the intervention impact on leader identity was not uniform across participants, based on class level. Some of these differences have already been discussed (e.g., leader identity increasing more for less interested upper-division students, lower-division students more impacted by relational leadership perspectives). Though the quantitative differences between lower-division and upper-division participants was mixed and inconclusive, important distinctions did emerge in further exploratory analysis and the qualitative data.

5.3.1. Lower division

Students in lower-division courses reported more dramatic shifts in their thinking about leadership, and they were also more likely to take binary approaches to leader identity. The dramatic shifts were a result of students being exposed to engineering leadership models for the first time. The instruction component of the intervention was important in introducing students to expansive and relevant leadership models that describe how engineers work together. This is especially important, as the ubiquity of heroic leadership models in popular culture contrasts with authentic practice in the engineering profession—this contrast may be even more problematic with the emergence of dynamic engineering personalities, such as Bill Gates and Elon Musk. With this informed view, students can more clearly understand the practices and values of the profession. This may be especially influential in reducing resistance to leadership for

those students who see leadership and engineering as inconsistent. An especially valuable aspect of this exposure to engineering practices was an increased appreciation for complex (i.e., specialized knowledge) and non-technical skillsets (i.e., professional skills) important to the profession.

One aspect of lower-division students that emerged as particularly impactful on their responses was the broad range of previous leadership experiences (as indicated by the high variance on this variable). Those with more previous leadership experience reported much greater change in leader identity. This is likely due to their increased familiarity with leader positions outside of engineering. This increased familiarity led to improved sense-making of relational and developmental views of leadership. This characteristic highlights the value of peer learning and reflection for lower-division students; more experienced students can share their perspective, and less experienced students can learn from a diverse viewpoint.

The drastic change that many lower-division participants reported highlights the need for younger students to be given a clearer idea of how leadership is practiced in the profession, and how it can be more effectively practiced in school. The binary approaches to engineering leadership are indicative of earlier stages in the LID model, which is appropriate given that these are lower-division students (Komives et al., 2005). However, this characteristic also highlights the importance of supporting students by scaffolding more complex behaviors and teaching them models of leadership in the profession. By introducing values and practices early, students are better equipped to pursue their professional training in more authentic ways.

Heterogeneity amongst participants also emerged related to lower-division major. While subsequent analysis demonstrated that the meaningful influence on leader identity was not major, but interest, the relationship is still important. If more lower-division students who are interested in leadership are drawn to industrial engineering (and not to computer science), the ways in which leadership should be presented may differ. Industrial engineering (and to a lesser extent, civil engineering) majors, with an interest in leadership, may need to be exposed to more expansive and appropriate ways of practicing it. Computer science majors (and to a lesser extent, chemical engineering and undecided majors), on the other hand, may by aided by being shown the importance of leadership in the profession. While the differences between majors seems to dissipate over time, addressing these differences early on may support healthy development. Here, cross-disciplinary groups may be especially impactful, as peers from diverse majors engage with one another.

5.3.2. Upper-division

Students in upper-division courses demonstrated more nuanced views of leader identity, characterized by smaller shifts in identity, more specific vocabulary, and more often identifying as emerging engineering leaders. Because of their broader range of experience (especially experiences related to engineering), they were able to integrate more complex leadership ideas into their understanding of leadership and themselves. This highlights the importance of providing students leadership frameworks that are robust and complex enough for them to integrate in various stages of development.

One feature of other outcomes (i.e., leadership interest, self-efficacy, and engineering identity) was their strong correlation with changes in leadership orientations amongst upper-division students (as opposed to lower-division students). The precise reason for these correlations is unknown. It may be that upper-division students have more integrated and understanding of leadership, so that more expansive models impact their perceptions in many ways. Or it may be that the SMART goal assignment facilitated an appreciation for the interconnectedness of power, development, and shared orientations of leadership. While qualitative data failed to address this characteristic, implementing the SMART goal assignment in lower-division groups would provide insight on this question.

In addition, one component of reflexive instruction was particularly influential for upper-division students. Providing upper-division students with a framework (SMART goal assignment) for pursuing their own development seemed impactful. Through it, students were able to identify specific skills that they wanted to cultivate, and they were able to see the impact of their success (or failure). This reflects the importance of students being able to exercise control over their own development, which can be cultivated by classroom activities that support and encourage independent growth. Activities that scaffold effective autonomous development support more advanced self-authorship (through taking responsibility for their own growth), sense of belonging in the profession (through engagement with professionally meaningful activities), and sense of leadership (through developing oneself). Peer discussion in group contexts allowed many participants to see the individualistic nature of leadership styles, in sharing both similar

and contrasting views. Providing appropriately complex models established appropriate vocabulary as tools for exploring more advanced ways of thinking about and practicing leadership. Finally, personal reflection led to both complexity of thought and individualistic views. For a handful of students, these experiences solidified and strengthened existing views of leadership, rather than changing them.

The difference between students of different class level highlights both the individualistic nature of development and the importance of authentic experiences for engineering students. Without these experiences, students are at a disadvantage both at understanding the profession and developing a clear vision for how they can meaningfully contribute. However, even with authentic experiences--as discussed previously-- students need to make sense of them to adopt more complex ways of seeing the world. Finally, the substantive impact of introducing students to authentic models of leadership highlights the need for (and appreciation of) presenting more robust and theoretically sound models of leadership.

5.3.3. Class Level Impact Summary

This study highlighted several differences between lower- and upper-division students that are important for understanding their engineering leadership development. While the engineering leadership literature and identity literature outline ways in which students mature, this research identified specific prominent characteristics that vary by class year and are especially meaningful for engineering leadership development. This research found several ways lower-division students benefit from authentic engineering leadership models, especially if they have previous leadership experience. Importantly,

lower-division students generally have primitive views of leadership and a wide range of perspectives; introducing them to the ways engineers practice is an effective way to help them align their views with those of the profession. In other words, they need a clear view of what engineers do. In addition, the research on leadership-based differences between engineering fields is limited (Handley et al., 2021). The present study has shown that interest in leadership tends to vary by engineering major as students enter their degree program; this finding may have important implications for practice, as programs strive to socialize students into their respective engineering fields (e.g., do students more need to understand the importance of leadership to their field, or to understand how to best think of leadership, or to have effective interpersonal engagement scaffolded for them?).

This research also identified ways in which upper-division students can be best supported in their engineering leadership development. This study found that these students benefited from taking responsibility for their own growth, but they needed scaffolding and support to take the necessary initiative. Finally, students often focused on interpersonal skill development when taking responsibility for their own growth

5.4. Discussion Summary

The impact of short-term reflexive instruction on metrics of engineering leadership was pervasive and meaningful. Participants were better able to see the relationship between engineering and leadership. Largely due to presenting authentic models, participants expanded their understanding beyond positional-based models. Because of these shifting perspectives, they began to see how leadership could be

developed and practiced during their education. Personal reflection and detailed discussion of various leadership styles facilitated this shift. Finally, students were able to appreciate the leadership process, understanding how both they and others could meaningfully contribute to project success. Group discussion of previous experiences provided context for adopting inclusive leadership frameworks. In sum, the substantive impact of this short-term intervention highlights that upper-division and lower-division students are well-positioned to learn, understand, and adopt authentic models of engineering leadership, if given appropriate support and guidance.

5.5. Theoretical Implications

The most important theoretical implication of this research involved the central role that the relationship between engineering and leadership plays in identity. Perception of leadership orientation (e.g., power, development, and shared) was initially suspected to be the strongest predictor of leader identity. However, the most widespread influence on identity was the relationship between engineering and leadership. This implies that alignment between personal and professional values are important to students in how they see themselves, as well as in the interest and self-efficacy they feel. Expansive models of leadership (beyond the charismatic hero) simply facilitate this alignment, as reflected by the strong correlations between leadership construct factors. However, more expansive views of leadership, in and of themselves, vary in their impact on engineering students' personal feelings on engineering leadership.

A second theoretical implication of this study relates to varied ways in which student leader identity is impacted. Lower-division students found that authentic

exploration of engineering leadership greatly expanded their understanding of the profession, with growth in relational views of leadership being especially important for identity. Upper-division students, on the other hand, found that discussion of leadership in the profession enriched their appreciation for engineering leadership, with increased belief in the dynamic aspect of leadership being especially important. Another difference between students depends on major for lower-division students. Different majors seem to attract individuals with varying levels of interest in leadership: industrial and civil engineering report higher interest, while chemical and computer science report lower interest. This heterogeneity of student experience and response highlights the dynamic and individualistic nature of identity.

5.6. Practical Implications

First and foremost, the substantive impact that this short term intervention had indicates that students are receptive to leadership development, and quite probably professional development overall. Incorporating group work, reflection, values, and vocabulary in instruction were powerful, even during a short instructional module. This is likely because existing traditional classroom models focus on knowledge accrual, rather than meaningful professional experiences—leaving student professional skills relatively undeveloped. This explanation resonates with existing critiques of traditional engineering education models, where technical training is isolated from a professional context. Fortunately, a powerful (even if partial) remedy seems to be quite simple: provide an informed exploration of the profession; guide personal reflection and professional vision; support group discussion and provide scaffolding and guidance. In

effect, this remedy is simply introducing students to the profession in a meaningful, authentic way. In addition, extending the scope of this approach would likely yield additional benefits. While engineering faculty may not all be equipped to lead such experiences, finding such experts need not be difficult if there are engineering firms in the area. In sum, this research offers a model for effective identity-based instruction.

The second practical implication relates to the nature of student development. Personal growth is unlike technical mastery in several ways: it is very difficult to assess, it is not linear, it is treacherous to demand, and levels of competence vary by individual. An identity-based approach to learning focuses on the student taking responsibility for their own individual growth. This framework effectively supports student development. However, the role of the instructor shifts: the responsibility of the educator is to cultivate a safe environment for meaningful exploration (e.g., highlighting the value of diverse experiences), to scaffold more developed ways of engaging with the world (e.g., provide case studies highlighting mature professional conduct), and to provide resources for individual growth (e.g., highlighting personal SMART goals). This research has shown that the four components of reflexive instruction positively impact identity: reflection, values, vocabulary, and group work. One important aspect of this approach is the allowance for non-engagement, as student choice to participate in a meaningful way is a necessary component of identity growth. This approach to teaching may be foreign to many technical educators who are accustomed to clear, measurable learning objectives. However, if we are to prepare engineering students for the profession (and life) responsibly, their overall identity development must be supported by their education.

5.7. Limitations

This study has four noteworthy limitations that impact efforts to generalize the findings to all engineering students; generalizability is limited by the degree with which the research sample reflects the overall population. First, convenience drove selection of courses in which reflexive instruction was implemented. Because convenience was influenced by instructor interest, the overall impact of the intervention may have been affected by a classroom environment that supported overall professional and personal growth. Therefore, the results seen may be positively biased due to alignment between intervention and course objectives. One solution to expose this possible bias is to research the effects of reflexive instruction across a broader range of engineering courses. A second (and possibly more enlightened) solution may be to cultivate faculty value for professional skill development in their courses.

Second, racial diversity (14% non-white participants) was substantially lower than the national ethnicity distribution of engineering students (39% non-white), despite the chosen institutions' focus on serving minorities (American Society for Engineering Education, 2020). This population characteristic may introduce two issues. The first issue is a limited experience of diverse perspectives due to race-based experiences. The second issue is limited understanding of the impact of expansive views of leadership on minority groups. This may be especially influential, as expansive views of professional roles may particularly benefit minoritized groups (e.g., Faulkner, 2007). Implementing this intervention in more diverse classrooms may further leverage the impact of diverse

perspectives on everyone, as well as the impact of expansive ways of knowing, being, and engaging on minoritized groups.

Likewise, gender distributions in the research population substantially differed from the national population (34% female vs 22.5%, respectively). Here, the increased proportion of females may impact the overall classroom environment in ways that differ from more homogeneous classes. One example of this impact might be increased experience working with other females in class, which can contribute to one's professional identity (Capobianco, 2006). Further studies in varied ratios of male to female classrooms could parse out mechanisms for professional identity development in more detail. Another option is to provide models of engaging with the profession that are equitable by gender, a solution recommended by others (e.g., Faulkner, 2000).

Finally, the distribution of majors was rather limited and did not reflect national data. Moreover, choice of major seemed to play an important role in leadership interest, with indications that leadership perception was also important. This, combined with the disparity of racial and gender-based distributions across engineering majors (American Society for Engineering Education, 2020, pp. 7-8), indicates this variable may be important in understanding mechanisms of professional identity development. Here, the limited sample size of this research was especially problematic in establishing adequate power to measure differences based on major. Moreover, several majors were not even included in this study (e.g., materials and aerospace). Implementing reflexive instruction in more classes across the engineering curriculum would address this limitation, as well. These final three limitations sources may have been further exacerbated by the use of

stepwise regression in analyses of Research Question 3. This has the potential to introduce a positive bias due to the possibility of random selection of control variables, even with the care taken in this study during the stepwise process (Tashakkori & Teddlie, 2010). It is hoped that future work that explores a larger population, thereby tempering this danger, will be able to more robustly explore the impact of other factors on leader identity development.

5.8. Delimitations

In addition to the four previous limitations, there were three ways in which this research is limited in applicability due to its design: these are delimitations, which are due to decisions made regarding study design and were therefore under my control. The first delimitation relates to the limited scope of the measures. While this decision provided focus to the research and lightened the burden of participation, it also limited the possible variables that could be measured. As a result, there is no quantitative data reflecting important aspects of leadership experience (e.g., level of responsibility, number of people under charge, quality of supervisor). While qualitative data provided excellent insight into the types of variables that influenced student identity, it is quite possible that many influential aspects of experience were not mentioned in the limited essays. This is especially important for lower-division students, as they exhibited a wide range of leadership experiences. Limited control variables also greatly limit the ability to explore causal mechanisms. Understanding identity development is complex, so being able to identify the impact of mediating and direct influences would be essential for

understanding leader identity development in more depth. As with the limitations, a larger sample size, with more control variables would facilitate this approach.

A second delimitation relates to the nature of direct, self-report measures on leadership and identity. Mainly, they may introduce various biases, based on student attitude, perceived judgments, etc. While this decision was made to lighten the burden of participation, indirect measures may provide a less biased assessment of student identity. Moreover, because this bias could be quantified, a solution may be to only implement this type of evaluation amongst a sub-sample of a broader research population.

A final delimitation was the choice of implementing an identity-based intervention short-term. While this decision is important for understanding the 'low-hanging fruit', for facilitating widespread implementation, and for limiting the scope of study, it is not without its consequences. The short-term nature of the measures leaves the longer-term impact of the intervention in question. Evaluation of student perception the following semester or year may provide insight into long-term impact of this intervention. In addition, a short-term approach to identity development is fraught with peril, given the complexity and dynamic aspect of identity. In contrast, longer term focus on this aspect of professional life may not only impact students more, but in different ways. Further research that takes a long-term approach to engineering leadership identity development would address this concern.

5.9. Future Research

Several pathways for future research emerged during reflection on this research and its results. They involve extending the research, addressing its limitations, and evaluating assumptions.

5.9.1. Research the Impact of a More Intensive Intervention

This research was intentionally limited in scope; however, the literature suggests that more invasive identity-based instruction may have a substantive impact on student development. Individualized instructor feedback may support identity growth on more advanced and complex topics (e.g., Nino, 2016). Comments on essay assignments would be an ideal pathway for this type of feedback. Finally, exploring the impact of reflexive instruction over a longer period may provide insight into identity-development processes that cultivate a leader identity.

It is important to note that a more controlled intervention could somewhat compromise generalizability to other populations that might use different interventions. This is because a more intensive intervention introduces additional control over the environment of and inputs to the students, as mentioned previously. While this may improve understanding of this particular intervention, that same control makes it difficult for researchers to generalize to other contexts that do not use an identical intervention. This is a reflection of the inherent trade-offs existent in naturalistic research (Tashakkori and Teddlie, 2010).

5.9.2. Research a Larger, More Varied Sample Population

Addressing the sampling limitations of the study would provide more generalizable findings. By extending the scope of the sample population, the experiences of minority groups and female students could be captured with more detail. Moreover, a greater sample size would enable measure of lower-effect control variables (especially with categorical sub-populations), which may identify important mechanisms of the relationships seen here. In addition, including partner institutions in this type of research would identify the degree to which individual contexts (e.g., different instructors, programs, demographics, institution types) may influence this particular approach of reflexive instruction. Finally, this approach may also clarify the validity of a reduced OTL-Power factor by reducing the confidence interval of Cronbach's alpha.

5.9.3. Research Student Response Under Different Assumptions

Finally, a quasi-experimental approach could be used to assess various components of the intervention. These could be implemented in multiple course sections, which would closely resemble random selection. For example, integrating the intervention with an authentic group project may provide a context for practicing various leadership approaches (e.g., Tallman et al., 2020). Related, combining reflexive instruction with traditional skill-based leadership training may be especially impactful for students. A control group could isolate the impact of perceived growth during the

semester. Different identity-based interventions could be trialed to identify those that have the greatest impact for lower-division or upper-division students.

5.9.4. Research Longer-term Impact

This research explored the short-term impact of reflexive instruction. This may or may not correlate with longer-term student responses to the intervention. Understanding long-term influences on identity is particularly important, as identity is thought to provide long-term influence on student motivation. Hence, additional research should outline the long-term impacts of reflexive instruction. It would be useful to understand the longitudinal trends engineering majors report as their leader identity develops during their college experience.

5.9.5. Evaluate Programmatic Approaches

This research was intended to be a first step to increase the field's understanding of engineering leadership development. This research suggests that using an identity lens provides an effective framework for evaluating how students perceive their own development. Given the importance of identity to continued leadership development, future researchers would be encouraged to use an identity measure to evaluate the effectiveness of their programmatic and curricular initiatives. For example, evaluating leader identity may provide a useful metric for quantifiably comparing the effectiveness of one leadership development approach with another one. This would furthermore

answer concerns about the lack of widespread leadership assessment techniques at a programmatic level.

5.10. Conclusion

The purpose of this dissertation was to examine the impact of identity-based interventions on engineering leader identity. These interventions were shown to substantially influence student leader identity and understanding about leadership. In addition, several details about this influence emerged through analysis of the data, leading to increased understanding about how to cultivate increased leader identity. While there were limitations to the study, it accomplished its goal of making initial contributions to our understanding of engineering leader identity development.

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APPENDICES

APPENDIX A

SUMMARY OF FOUR IDENTITY FIELDS

	Characteristic	Personal Identity	Professional Identity	Engineering Identity	Leadership Identity
Theoretical Framework		Kegan's 6 orders of self-consciousness	COP	PCIR	LID
Developmental Process		Self-authorship; Meaning making	Belonging	Commitment & competence	Differentiation
Stages	First-year	Co-construct knowledge	Discover community; practice as novice	Uncertainty in path; focus on technical skills	Position
	Senior	Construct knowledge	Participate; practice expertise	Practice	Relational
Practice	Reflection	Cultivates and resolves tension shifts locus of control (beliefs	is a response to expert feedback	Provides recognition of competence.	Facilitates awareness of all growth; Supported via feedback and mentorship.
	Authentic Experience	shifts locus of control (action)	is the context for learning by doing	increase perspective and align values.	Instrumental in complex skill growth
	Scaffold	provides needed support for complex meaning making	is provided by experts to beginners		Facilitates more complex thinking
	Peer learning	Facilitates ownership of knowledge; provides support; encourages differing perspectives.	Essential for ownership of education, as one leaves the shelter of didactic caretakers.	Cultivate sense of belonging Develop social navigation	Cultivates engagement; Illuminate interdependence need; Connects one to transcendence.
	Differing Perspective	promotes growth in reflective thinking; facilitates perspective shifts.	regarding the complexity and heterogeneity of the trade develops		
	Tool & Language		are explored, learned, and adopted.		Important to discuss to envision growth
	Values		are explored, learned, and adopted.	Align with identity, connects to interest	Shift from control to shared vision
	Technical Skills			Build self-efficacy. Function as gateway	
	Social Skills			Are a value in sociotechnical professions. Mediate recognition and belonging.	Empower collaboration and influence

APPENDIX B

SLR METHOD DETAILS

Criteria	Details
Databases	ProQuest, Google Scholar, Wiley, Taylor Francis, Science Direct, Compendex, Web of Science, Ebsco
Search tools used	Truncate, near, abstract/text options
Precision vs. Sensitivity	Precision over sensitivity due to large amount of surrounding, but irrelevant literature (vs. preference for sensitivity for sake of comprehensive approach)

APPENDIX C

SLR FINAL SEARCH CRITERIA

Database	Search Term Used	Details	Total Results	Title Relevant	Abstract Relevant	FINAL SET
ProQuest	noft(engineer* n/4 leader*) AND noft(identity)	None	96	33	23	19
Wiley online	Engineer* AND leader* AND identity in Abstract engineer* AND (leader* OR identity) in Title	Articles and Chapters tab	12	7	4	2
Taylor Francis	engineer* AND (leader* OR identity) in Title 'leader' in keywords	Articles tab	17	11	6	2
Science Direct	(engineer OR engineering) AND (lead OR leader OR leadership) AND (identities OR identity)	None	36	2	0	0
Compendex	((AB=engineer* leader*) OR (AB=scien* leader*)) AND (AB=self*)	None	34	0	0	0
Web of Science	(TI=engineer* leader* identit*) OR (TI=engineer* leader* self-*) OR (AB=engineer* leader* identit*)	Abstract--No self-*, n=637	146	23	12	6
EbscoHost	((engineer* N4 leader*) OR (scien* N4 leader*)) AND (identity* OR self-*)	None	266	44	24	11
Overall			607	120	69	40

APPENDIX D

SLR SCOPING LITERATURE OVERVIEW

Title	First Author	Year	Main Ideas	Theoretical lens
An Approach to Understand the Role of Identity in Engineering Leadership	Schell	2017	Mixed methods research to establish a grounded theory of engr. leader identity development	LID, CoP, Senge's Fixes that fail, PCIR, 3 E L Constructs (Rottmann)
Engineering leadership: grounding leadership theory in engineers' professional identities	Rottmann	2015	Grounded theory of prof. engr. ldrs.: Technical mastery, Collaborative Optimization, Organizational Innovation	Identity
Social Identity Development and the Situation of Scientists and Engineers as New Leaders	Racine	2015	Qual.research of new leaders: Tech. competence, Prototypical, ldr proficiency	Social Identity Theory.
Bioengineering Student Leader identity Via Training and Practice within the Core-Course	Rosch	2016	Ldrship training and practice in classroom impacts Ldr ID, but MTL less. Group org. matters	Leader identity, Motivation to Lead

APPENDIX E

SLR EXCLUSION CRITERIA

Reason	Quantity
Not engineering students	2
Not Identity	16
Not students	2
Not Engineering identity	1
Not developmental focus	3
Not English	3
Total	27

APPENDIX F

ENGINEERING LEADERSHIP ORIENTATIONS

Leadership Orientation (Rottmann)	**Influence level (Racine, 2015)**	**Value / contribution (Mumford, Scott, Gaddis, & Strange, 2002)**	**Social Identity (Hogg, 2001)**	**Scientific Leadership (Robledo, Peterson, & Mumford, 2012)**
Technical mastery	Dyad (mentor)	Craftsman	Self (Technical)	Work
Collaborative Optimization	Group (catalyst)	Quality / Network	Peers (Prototypical)	Group
Organizational innovation	Organization (entrepreneur)	Strategy / Vision	Discipline (Ldr Proficiency)	Organization

APPENDIX G

SLR FULL LITERATURE OVERVIEW

Title	Authors
Leading from the Bottom Up: Leadership Constructs and Practices Among Early Career Engineers	Klassen, Mike; Kovalchuk, Serhiy; Reeve, Doug; Sacks, Robin
An Approach to Understand the Role of Identity in Engineering Leadership	Schell, William J, IV; Hughes, Bryce E
Developing Engineering Leaders Using a Reflective Autobiographical Exercise	Niño, David
Charting the Landscape of Engineering Leadership Education in North American Universities	Klassen, Mike; Reeve, Doug; Rottmann, Cindy; Sacks, Robin; Simpson, Annie Elisabeth; Huynh, Amy
Engineering Leadership as Principled Nonconformity	Neeley, Kathryn A
INVENTION EDUCATION AND THE DEVELOPING NATURE OF HIGH SCHOOL STUDENTS; CONSTRUCTION OF AN IDENTITY	Couch, Stephanie; Skukauskaite, Audra; Estabrooks, Leigh B
Exploring the Relationship Between Students' Engineering Identity and Leadership Self-Efficacy	Schell, William J, IV; Hughes, Bryce E; Tallman, Brett; Annand, Emma; Beigel, Romy M; Kwapisz, Monika B
Development of Leadership Self-Efficacy: Comparing Engineers, Other STEM, and Non-STEM Majors	Hughes, Bryce E; Schell, William J; Tallman, Brett
A PHENOMENOLOGICAL INQUIRY INTO ENGINEERS MOTIVATION TO LEAD	Ulrich, Thomas R
Understanding the Perceived Impact of Engineers' Leadership Experiences in College	Schell, William J, IV; Hughes, Bryce E; Tallman, Brett
Examining the Engineering Leadership Literature: Community of Practice Style	Rottmann, Cindy; Reeve, Doug; Klassen, Mike; Kovalchuk, Serhiy; Liu, Qin; Olechowski, Alison; Santia, Madeleine
Board 130: The Formation of Undergraduate Engineers as Engineering Leaders	Schell, William J, IV; Hughes, Bryce E; Tallman, Brett

Title	Authors
ARE ENGINEERS' LEADERSHIP ATTITUDES AND EXPERIENCES DIFFERENT THAN OTHER STUDENTS?	Schell, William J, PhD, PE, PEM; Hughes, Bryce E, PhD
Travel grants which facilitate engineering leader identity in female engineering students	Serrano, Mayari I; Groh, Jennifer L
Board 139: Engineering Leader identity: A Qualitative Approach to Understand the Intersection of Engineering and Leadership Identities	Beigel, Romy; Annand, Emma; Kwapisz, Monika; Schell, William J, IV; Hughes, Bryce E; Tallman, Brett
THE EFFECT OF ENGINEERING LEADER IDENTITY RESEARCH ON THE IDENTITIES OF STUDENT RESEARCHERS	Kwapisz, Monika; Sybesma, Tessa; Annand, Emma; Ranch, Shannon; Beigel, Romy; Schell, William; Tallman, Brett; Hughes, Bryce
Engineering Leadership and Entrepreneurial Personality	Edwards, Thomas V, Jr; Pillapakkam, Shriram
Engineering leadership: grounding leadership theory in engineer's professional identities	Rottmann, Cindy; Sacks, Robin; Reeve, Douglas
Social Identity Development and the Situation of Scientists and Engineers as New Leaders	Racine, William P
Creating an Instrument to Measure Leadership, Change, and Synthesis in EngineeringUndergraduates	Ahn
A Comparative Analysis of Defensive Routines in Engineering Managers Versus Non-Engineering Managers	Riley
Bioengineering Student Leader identity Via Training and Practice within the Core-Course	Rosch
Curricular and Co-curricular Influences on Undergraduate Engineering Student Leadership.	Knight, David B.; Novoselich, Brian J.
Curricular and Co-Curricular Leadership Learning for Engineering Students	Reeve, Doug; Evans, Greg; Simpson, Annie; Sacks, Robin; Olivia-Fisher, Estelle; Rottmann, Cindy; Sheridan, Patricia
Developing Leaders by Putting Students in the Curriculum Development Driver Seat.	Montoya, Yazmin; Pacheco Rimada, Aaron Eduardo; Delgado, Erwin; Webb, Isaiah Nathaniel; Vaughan, Meagan R.

Title	Authors
Purposeful Leadership: The Life Calling of Successful Women Scientists	West, Ja-Quel April
What Do Students Experience as Peer Leaders of Learning Teams?	Johnson, Erik C.; Robbins, Brett A.; Loui, Michael C.

APPENDIX H

PILOT THEMES

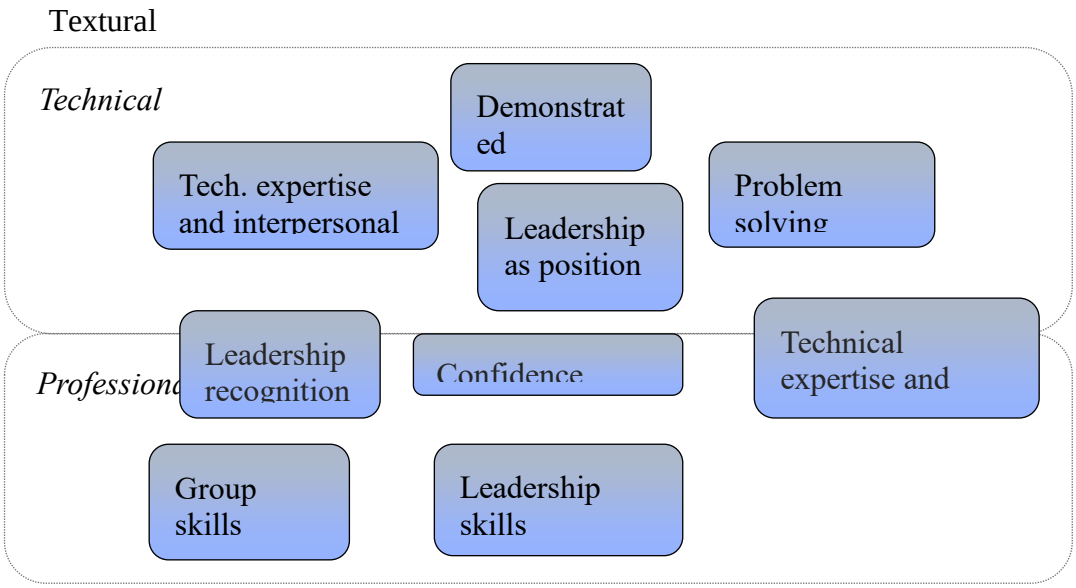

Figure 1, Textural Themes

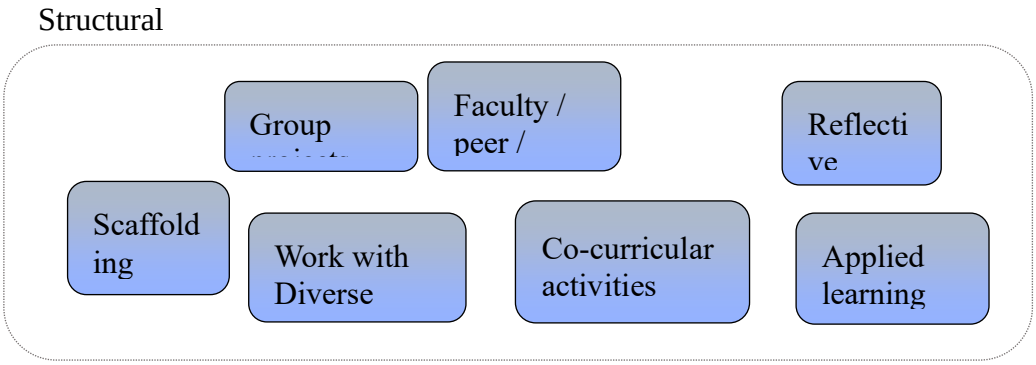

Figure 2, Structural Themes

APPENDIX I

SURVEY VARIABLES

Variable	Response Type	Research Question
Demographics (5 items)	Text	N/A
Leader identity (7 items)		
LSI, Descriptiveness (4 items)	7-item Likert-type	RQ1, 3, 4
LSI, Importance (3 items)	7-item Likert-type	RQ1, 3, 4
Construct (12 items)		
OTL, Process (4 items)	7-item Likert-type	RQ2, 3, 5
OTL, Learned (4 items)	7-item Likert-type	RQ2, 3, 5
OTL, Power (3 items)	7-item Likert-type	RQ2, 3, 5
Engineering Leadership Relationship	8-item Likert-type	RQ2, 3, 5
Other outcomes		
Interest (1 item)	7-item Likert-type	N/A
Self-efficacy (1-item)	7-item Likert-type	N/A
Engineering identity (1-item)	8-item Likert-type	N/A
Controls		
Demographics (3-items)	Various	N/A
Leadership Experience (3-items)	7-item Likert-type	N/A
Control Question (1-item)	7-item Likert-type	N/A

APPENDIX J

OUTLOOK ESSAY ASSIGNMENT

Engineering Leadership, Homework 1 **ENGR Xxx, Spring 2021**

Directions:
[1-page maximum. Write an essay that answers both questions posed below. Justify your responses with at least two specific examples. The assignment will be graded on completion only—no penalties for grammar mistakes or weak style. However, your submitted work should represent an honest and sincere effort —so put your best foot forward!]

Essay Questions:

1. How would you define engineering leadership?

2. Would you consider yourself as-– or becoming– an emerging engineering leader? If so, in what way? If not, why not?

APPENDIX K

LOWER-DIVISION LESSON PLAN

Topic:	0.3 Class Discussion (Engr. Ldrship, Lower-division) v1
Learning Targets:	Understand different types of positional leadership; Understand relational leadership; Understand three types of engineering leadership.
Class prep/resources:	Post and assign videos
Pre-video	Three videos on leadership: Authoritarian, Democratic, & Laissez Faire; Positional vs. Relational; and Tech. Mastery, Coll. Opt., and Org. Innov.
Pre-Reading:	Completion of Pre-survey and Outlook Essay
Homework due:	Prepared to discuss type of engineering leader that is most interesting to you.

Activity	Purpose	Time
Welcome to class. Introduce today's topic-- engineering leadership.	Transition into class, intro.	3
Quiz-- three types of englineering leadership; 2 types of positional leadership; difference between positional vs. relational. [App. 1]	Focus, reflect, review content	7
Group Activity [Appendix 2]	Explore E L types with partner(s)	30
Class-wide Discussion of engienering leadership types. 2-3 interesting comments from groups. Instructor normalizes terms: leadership, influence, responsibility, interdependence. Normalize action: get involved in a professionally interesting project (list examples, maybe even with contact info). What to do now? What are barriers?	Review, action items, talk.	10
Homework: Reflection Essay, then post-test survey [App. 3]	Reflection of growth / measure	
	Total	50

Appendix 1: Formative Quiz

1. List 2 types of positional leadership types.
2. In one sentence, describe the difference between positional and relational leadership
3. List 3 types of engineering leadership (descriptions are acceptable.

Appendix 2: Group work

1. Take 2 minutes to talk about the quiz with your partner. Go over answers as a class (students provide answers). Questions?
2. Take 2 minutes in silence to consider:
    a. What type of engineering leader do you envision yourself becoming? Why?
3. Interview your partner for 3 minutes on this topic.
4. Switch roles.
5. Merge with another group.
6. Each of the four of you will now present a 3 minute summary of your partner's perspective on the question.

Appendix 3: Homework 2, Reflection Essay

Engineering Leadership, Homework 2 **ENGR 1xx, Spring 2021**

Directions:
1-2 pages. Reread your first essay (Homework 1). Write an essay that answers both questions posed below. Justify your responses with at least two specific examples. Again, the assignment will be graded on completion only—no penalties for grammar mistakes or weak style. However (again), your submitted work should represent an honest and sincere effort —so put your best foot forward!

Essay Questions:

1. How has your perspective on engineering leadership changed / strengthened / weakened since your first essay?

2. Which-- if any-- practical steps (that were discussed in class) sound personally interesting

DUE: 1 week.

APPENDIX L

UPPER-DIVISION LESSON PLAN 1

Topic:	4.3 Class Discussion (Engr. Ldrship, Upper-division) v1
Learning Targets:	Understand relational leadership vocabulary, ; Understand three types of engineering leadership.
Class prep/resources:	Post and assign videos
Pre-video	**Required**: Two videos on leadership: Positional vs. Relational; and Tech. Mastery, Coll. Opt., and Org. Innov.
Pre-Reading:	Completion of Pre-survey and Outlook Essay
Homework due:	Outlook essay done. Prepared to discuss type of engineering leader that is most interesting to you.

Activity	Purpose	Time
Welcome to class. Introduce today's topic-- engineering leadership.	Transition into class, intro.	3
Quiz-- three types of englineering leadership; difference between positional vs. relational. [App. 1]	Focus, reflect, review content	6
Group Round Robin [App. 2]	Explore E L types with group	30
Class-wide Discussion of engineering leadership types. 5-10 interesting next steps from groups (by each of 3 E L orientations). Any brilliant insights on next steps, from group? Instructor normalizes terms: leadership, influence, responsibility, interdependence. Normalize action: practice leadership, develop skills (list examples, maybe even with contact info). SMART goal introduction	Review, action items, talk.	10
Homework: Practical step assignment, HW 2[App. 3]		
	Total	49

Appendix 1: Formative Quiz

1. In one sentence, describe the difference between positional and relational leadership
2. List 3 types of engineering leadership (descriptions are acceptable).

Appendix 2: Group work, Round Robin

1. Take 2 minutes to talk about the quiz with your group. Go over answers as a class (students provide answers). Questions?
2. Take 2 minutes in silence to consider:
    a. What practical steps might one take to develop in one of these three engineering leader orientations?
3. Round Robin, 5 minutes.
    a. Choose a scribe.
    b. Clockwise, brainstorm one idea per person. How many rounds can you do?
4. Share Round Robin results with class.

Appendix 3: Practical Step Assignment, HW2

Engineering Leadership, Homework 2 **ENGR 4xx, Spring 2021**

Directions:

In your team:

Discuss which type of engineering leader you envision yourself becoming (possibly)? Why?

On your own:

1. Describe one practical step you will take to develop this semester as an engineering leader (consider your team discussion).
2. Set a SMART goal to accomplish this step:
    a. S- Specific (i.e., what do you want to accomplish—make it simple & clear)
    b. M- Measurable (i.e., how will you know if you've succeeded)
    c. A- Achievable (i.e., make it realistic, but also challenging)
    d. R- Relevant (i.e., is this goal compelling, for you, right now)
    e. T- Timely (i.e., by when? This goes with M and A—what challenge will you accomplish by when?)
3. Submit a paragraph describing your goals, from #1 and #2.

DUE: Next class period. Come prepared to discuss your goal.

Again, the assignment will be graded on completion only—no penalties for grammar mistakes or weak style. But you do need to address all 5 aspects of the SMART goal.

p.s.—Pro tip-- Feel free to use a leadership goal that you are already working on…

APPENDIX M

UPPER-DIVISION LESSON PLAN 2

Topic:	4.4 Summary Class Discussion (Engr. Ldrship, Upper-division) v1
Learning Targets:	Explore and commit to growing in a particular E L construct. Identity a personally meaningful developmental step.
Class prep/resources:	Watched videos.
Pre-video	**N/A**,
Pre-Reading:	N/A.
Homework due:	One sentence practical step you plan on taking. Prepared to discuss type of engineering leader that you envision yourself becoming.

Activity	Purpose	Time
Welcome to class. Introduce today's topic-- engineering leadership summary and practical steps. Students to summarize positional vs. relational. And 3 orientations.	**Transition into class, intro.**	**3**
Open with list of interesting next steps from group-- from last class session. Working through this is hard-- support your team mates, and share your ideas. For each orientation / next steps, ask for a volunteer to share their SMART goals. Any extras? Questions? Remind students of Reflective Essay (w/ practical step)	**Share goals, normalize behavior**	**12**
Homework: Reflective Essay-- in 4-10 weeks. [Appendix 1]	**Reflection. Just a brief reminder during this class period to emphasize the practical step is important.**	
	Total	**15**

Appendix 1: Reflective Essay

Engineering Leadership, Homework 3 **ENGR 4xx, Spring 2021**

Directions:
1-2 pages. Reread your first essay (HW 1) and your practical step / SMART goal (HW 2). Write an essay that answers both questions posed below. Justify your responses with at least two specific examples. The assignment will be graded on completion and addressing your SMART goals (not necessarily accomplishing them, just make sure you discuss the outcome). However, as before, your submitted work should represent an honest and sincere effort —so put your best foot forward!

Essay Questions:
Review your first reflection essay & practical step (incl. SMART goals). Consider your team discussions.

1. How has your perspective on engineering leadership changed / strengthened / weakened over this semester (include discussion of your practical step and SMART goals)?

2. Which-- if any-- practical steps (that were discussed in class or in your team) sound personally interesting to you going forward?

DUE: TBD.

APPENDIX N

PRE-SURVEY

Pre-Survey

Survey to be administered electronically.

Please answer the following questions. All questions are optional, and you may skip any that you are not comfortable answering.

1. What is your name?
2. What is your major?
3. What is your class year?
4. Please provide your gender identity.
5. Please provide your race / ethnic identity.

The following items ask about your beliefs about the nature of leadership. Please respond using the scale below, from 1 (strongly disagree) to 7 (strongly agree).
[1- Strongly disagree; 2- Disagree; 3- Somewhat Disagree; 4- Neither Agree nor Disagree; 5- Somewhat Agree; 6- Agree; 7- Strongly Agree]

6. Leaders order other people around.
7. Leadership happens when people collaborate.
8. Leadership and power are pretty much the same thing.
9. People can be taught to be more effective leaders.
10. Skills and abilities for leadership can be developed.
11. Leadership is a property of the group, not the individual.
12. Leadership involves a group collectively making decisions.
13. Leadership is the responsibility of everybody in a group.
14. One's formal position determines whether they are a leader.
15. Leaders can acquire skills to make them more effective.
16. You can't teach leadership.

Please rate the extent to which the following statements describe you, using a scale from 1 (not at all descriptive) to 7 (extremely descriptive).
[1- Not at all descriptive; 4- Moderately descriptive; 7- Extremely descriptive]

17. "I am a leader"
18. "I see myself as a leader"
19. "If I had to describe myself to others, I would include the word 'leader' "
20. "I prefer being seen by others as a leader"
21. This is a control question. Please choose response 2.

Think about your overall self-concept. How important are each of the statements to your self-identity. Answer the following questions below, from 1 (not at all important) to 7 (extremely important).
[1- Not at all important; 4- Moderately important; 7- Extremely important]

22. "I am a leader"
23. "I see myself as a leader"
24. "I prefer being seen by others as a leader"
25. To what extent does your sense of what a leader is (i.e., the identity of a leader) overlap with your sense of what an engineer is (i.e., the identity of an engineer)? The scale goes from 1 (Not at all) to 8 (To a great extent).

Please rate the extent to which the following statements describe you, using a scale from 1 (not at all descriptive) to 7 (extremely descriptive).
[1- Not at all descriptive; 4- Moderately descriptive; 7- Extremely descriptive]

26. I am interested in developing leadership.
27. I can be a leader.

28. To what extent does your sense of who you are (i.e., your personal identity) overlap with your sense of what an engineer is (i.e., the identity of an engineer)? The scale goes from 1 (Not at all) to 8 (To a great extent).
29. Think about your own leadership experience. Have you held a leadership position, or were you expected to advise, guide, direct, teach, manage or supervise other students in an organization or group?
[Yes, No]
If 'Yes' to Question 29,
For the following questions, let's call this your *leadership role*. In response to the previous question, you indicated that you have held a leadership role in a student organization or group. If you had more than one role like this, base your answers on the one that is most memorable to you.
30. To what extent were the activities of this role associated with your academic program?
[4 = Very much, 3 = Quite a bit, 2 = Some, 1 = Very little]

In your leadership role, about how often did you do the following?
[4 = Very Often, 3 = Often, 2 = Sometimes, 1 = Never]
31. Include experiences from this role in your coursework or course discussions?
32. Interact with people from a background different than your own (social, racial/ethnic, religious, etc.)

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APPENDIX O

POST-SURVEY

Post-Survey
Survey to be administered electronically.

Please answer the following questions. All questions are optional, and you may skip any that you are not comfortable answering.

1. What is your name?

The following items ask about your beliefs about the nature of leadership, as you believe now (Present), and as you believed at the beginning of the course (Then). Please respond using the scale below, from 1 (strongly disagree) to 7 (strongly agree).
[1- Strongly disagree; 2- Disagree; 3- Somewhat Disagree; 4- Neither Agree nor Disagree; 5- Somewhat Agree; 6- Agree; 7- Strongly Agree]

2. Leaders order other people around. Believe NOW.
3. Leaders order other people around. Believe BEFORE the course.
4. Leadership happens when people collaborate. Believe NOW.
5. Leadership happens when people collaborate. Believe BEFORE the course.
6. Leadership and power are pretty much the same thing. Believe NOW.
7. Leadership and power are pretty much the same thing. Believe BEFORE the course.
8. People can be taught to be more effective leaders. Believe NOW.
9. People can be taught to be more effective leaders. Believe BEFORE the course.
10. Skills and abilities for leadership can be developed. Believe NOW.
11. Skills and abilities for leadership can be developed. Believe BEFORE the course.
12. Leadership is a property of the group, not the individual. Believe NOW.
13. Leadership is a property of the group, not the individual. Believe BEFORE the course.
14. Leadership involves a group collectively making decisions. Believe NOW.
15. Leadership involves a group collectively making decisions. Believe BEFORE the course.
16. Leadership is the responsibility of everybody in a group. Believe NOW.
17. Leadership is the responsibility of everybody in a group. Believe BEFORE the course.
18. One's formal position determines whether they are a leader. Believe NOW.
19. One's formal position determines whether they are a leader. Believe BEFORE the course.
20. Leaders can acquire skills to make them more effective. Believe NOW.
21. Leaders can acquire skills to make them more effective. Believe BEFORE the course.
22. You can't teach leadership. Believe NOW.
23. You can't teach leadership. Believe BEFORE the course.

Please rate the extent to which the following statements describe you, as you perceive now (Present), and as you perceived at the beginning of the course (Then), using a scale from 1 (not at all descriptive) to 7 (extremely descriptive).
[1- Not at all descriptive; 4- Moderately descriptive; 7- Extremely descriptive]

24. "I am a leader" Describe NOW.
25. "I am a leader" Describe BEFORE the course.
26. "I see myself as a leader" Describe NOW.
27. "I see myself as a leader" Describe BEFORE the course.
28. "If I had to describe myself to others, I would include the word 'leader' " Describe NOW.
29. "If I had to describe myself to others, I would include the word 'leader' " Describe BEFORE the course.
30. "I prefer being seen by others as a leader" Describe NOW.
31. "I prefer being seen by others as a leader" Describe BEFORE the course.
32. This is a control question. Please choose response 4.

Think about your overall self-concept. How important are each of the statements to your self-identity, as you believe now (Present), and as you believed at the beginning of the course (Then)? Answer the following questions below, from 1 (not at all important) to 7 (extremely important).
[1- Not at all important; 4- Moderately important; 7- Extremely important]

33. "I am a leader" Important NOW.
34. "I am a leader" Important BEFORE the course.
35. "I see myself as a leader" Important NOW.
36. "I see myself as a leader" Important BEFORE the course.
37. "I prefer being seen by others as a leader" Important NOW.
38. "I prefer being seen by others as a leader" Important BEFORE the course.

39. To what extent does your sense of what a leader is (i.e., the identity of a leader) overlap with your sense of what an engineer is (i.e., the identity of an engineer)? The scale goes from 1 (Not at all) to 8 (To a great extent). Believe NOW.

40. To what extent does your sense of what a leader is (i.e., the identity of a leader) overlap with your sense of what an engineer is (i.e., the identity of an engineer)? The scale goes from 1 (Not at all) to 8 (To a great extent). Believe BEFORE the course.

Please rate the extent to which the following statements describe you, as you believe now (Present), and as you believed at the beginning of the course (Then), using a scale from 1 (not at all descriptive) to 7 (extremely descriptive).
[1- Not at all descriptive; 4- Moderately descriptive; 7- Extremely descriptive]

41. I am interested in developing leadership. Describe NOW.
42. I am interested in developing leadership. Describe BEFORE the course.

43. I can be a leader. Describe NOW.
44. I can be a leader. Describe BEFORE the course.

45. To what extent does your sense of who you are (i.e., your personal identity) overlap with your sense of what an engineer is (i.e., the identity of an engineer)? The scale goes from 1 (Not at all) to 8 (To a great extent). Believe NOW.

46. To what extent does your sense of who you are (i.e., your personal identity) overlap with your sense of what an engineer is (i.e., the identity of an engineer)? The scale goes from 1 (Not at all) to 8 (To a great extent). Believe BEFORE the course.

47. Think about your own leadership experience this semester. Have you held a leadership position, or were you expected to advise, guide, direct, teach, manage or supervise other students in an organization or group?
    [Yes, No]

    If 'Yes' to Question 47,
    For the following questions, let's call this your *leadership role* (this semester). In response to the previous question, you indicated that you have held a leadership role in a student organization or group. If you had more than one role like this, base your answers on the one that is most memorable to you.

48. To what extent were the activities (this semester) of this role associated with your academic program?
    [4 = Very much, 3 = Quite a bit, 2 = Some, 1 = Very little]

    In your leadership role (this semester), about how often did you do the following?
    [4 = Very Often, 3 = Often, 2 = Sometimes, 1 = Never]

49. Include experiences from this role in your coursework or course discussions?

50. Interact with people from a background different than your own (social, racial/ethnic, religious, etc.)

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APPENDIX P

SLR LITERATURE CATEGORIZATION

Title	Authors		Reflection	Experience	Scaffolding	Group Work	Diverse Perspectives	Language	Values	Technical Skills	Social Skills
Leading from the Bottom Up: Leadership Conceptions and Practices Among Early Career Engineers	Klassen, Mike; Kovalchuk, Serhiy; Reeve, Doug; Sacks, Robin		X	X			x				X
An Approach to Understand the Role of Identity in Engineering Leadership	Schell, William J, IV; Hughes, Bryce E										
Developing Engineering Leaders Using a Reflective Autobiographical Exercise	Niño, David		X			X					X
Charting the Landscape of Engineering Leadership Education in North American Universities	Klassen, Mike; Reeve, Doug; Rottmann, Cindy; Sacks, Robin; Simpson, Annie Elisabeth; Huynh, Amy		x	x	x	x	X	X	X		X
Engineering Leadership as Principled Nonconformity	Neeley, Kathryn A						x	x	x		X
Invention Education And The Developing Nature Of High School Students; Construction Of An Identity	Couch, Stephanie; Skukauskaite, Audra; Estabrooks, Leigh B			X	X	X					
Exploring the Relationship Between Students' Engineering Identity and Leadership Self-Efficacy	Schell, William J, IV; Hughes, Bryce E; Tallman, Brett; Annand, Emma; Beigel, Romy M; Kwapisz, Monika B		x	x		x	x				x
Development of Leadership Self-Efficacy: Comparing Engineers, Other STEM, and Non-STEM Majors	Hughes, Bryce E; Schell, William J; Tallman, Brett			x		x					

Title	Authors		Reflection	Experience	Scaffolding	Group Work	Diverse Perspectives	Language	Values	Technical Skills	Social Skills
A PHENOMENOLOGICAL INQUIRY INTO ENGINEERS MOTIVATION TO LEAD	Ulrich, Thomas R		x			X	x	x	x		X
Understanding the Perceived Impact of Engineers' Leadership Experiences in College	Schell, William J, IV; Hughes, Bryce E; Tallman, Brett			x		x	x				
Examining the Engineering Leadership Literature: Community of Practice Style	Rottmann, Cindy; Reeve, Doug; Klassen, Mike; Kovalchuk, Serhiy; Liu, Qin; Olechowski, Alison; Santia,		x	x	X	X	x		x		X
Board 130: The Formation of Undergraduate Engineers as Engineering Leaders	Schell, William J, IV; Hughes, Bryce E; Tallman, Brett										x
ARE ENGINEERS' LEADERSHIP ATTITUDES AND EXPERIENCES DIFFERENT THAN OTHER STUDENTS?	Schell, William J, PhD, PE, PEM; Hughes, Bryce E, PhD										x
Travel grants which facilitate engineering leadership identity in female engineering students	Serrano, Mayari I; Groh, Jennifer L				x			x	x		

Title	Authors		Reflection	Experience	Scaffolding	Group Work	Diverse Perspectives	Language	Values	Technical Skills	Social Skills
Board 139: Engineering Leadership Identity: A Qualitative Approach to Understand the Intersection of Engineering and Leadership Identities	Beigel, Romy; Annand, Emma; Kwapisz, Monika; Schell, William J, IV; Hughes, Bryce E; Tallman, Brett				x						
The Effect Of Engineering Leadership Identity Research On The Identities Of Student Researchers	Kwapisz, Monika; Sybesma, Tessa; Annand, Emma; Ranch, Shannon; Beigel, Romy; Schell, William; Tallman, Brett; Hughes, Bryce		x						x		
Engineering Leadership and Entrepreneurial Personality	Edwards, Thomas V, Jr; Pillapakkam, Shriram		x		x			x			
Engineering leadership: grounding leadership theory in engineers' professional identities	Rottmann, Cindy; Sacks, Robin; Reeve, Douglas							x	x	x	x
Social Identity Development and the Situation of Scientists and Engineers as New Leaders	Racine, William P		x	x	X	X		x			X
Creating an Instrument to Measure Leadership, Change, and Synthesis in Engineering Undergraduates	Ahn	_					X				
A Comparative Analysis of Defensive Routines in Engineering Managers Versus Non-Engineering Managers	Riley				X			x			X

Title	Authors		Reflection	Experience	Scaffolding	Group Work	Diverse Perspectives	Language	Values	Technical Skills	Social Skills
Bioengineering Student Leadership Identity Via Training and Practice within the Core-Course	Rosch		X	X		X		x			X
Curricular and Co-curricular Influences on Undergraduate Engineering Student Leadership.	Knight, David B.; Novoselich, Brian J.					X					
Curricular and Co-Curricular Leadership Learning for Engineering Students	Reeve, Doug; Evans, Greg; Simpson, Annie; Sacks, Robin; Olivia-Fisher, Estelle; Rottmann, Cindy; Sheridan,		X								X
Developing Leaders by Putting Students in the Curriculum Development Driver Seat.	Montoya, Yazmin; Pacheco Rimada, Aaron Eduardo; Delgado, Erwin; Webb, Isaiah Nathaniel; Vaughan, Meagan		X	X		X					
Purposeful Leadership: The Life Calling of Successful Women Scientists	West, Ja-Quel April										X
What Do Students Experience as Peer Leaders of Learning Teams?	Johnson, Erik C.; Robbins, Brett A.; Loui, Michael C.		X		x	x	x	x		x	
Totals	27 sources		13	10	9	13	9	10	7	2	15

APPENDIX Q

IRB CONSENT

SUBJECT CONSENT FORM
FOR
PARTICIPATION IN HUMAN RESEARCH AT
MONTANA STATE UNIVERSITY

Examining Undergraduate Engineering Leadership Identity Development

Introduction – You are being asked to participate in a research study to understand how undergraduate engineering students view leadership in an engineering context. This includes how leadership is defined in engineering and how it relates to engineering identity. The study is expected to help engineering educators understand the development of engineering leadership skills and identity. The results of this study will be used to understand one educational approach to improve the development of leadership skills and identity in undergraduate engineering students. You have been asked to participate because you are an undergraduate engineering student.

Procedure - Participation is voluntary and there is no cost to you to participate. If you agree to participate you will be asked to complete one survey initially, and a second survey after the activity. In addition, your participation during the class session, including the relevant homework, will be recorded. Participation is voluntary and you can choose to not answer any survey questions you do not want to answer and/or you can stop at any time.

Risks and Benefits – While group and class instructions will be not to share anything said during group interaction and class time, there is a risk that other participants of the group or class could disclose the things that were said-- during group meetings or class-- to those who were not there. If there are questions you wish to answer in a private setting, individual discussion can be arranged. Along with the satisfaction of furthering engineering research, those who complete this study will receive one homework credit, contingent upon course instructor approval.

Decline to Participate - If you decline to participate, you may skip the surveys, and your responses as part of class activity will not be recorded. The class and group activities-- as well as relevant discussion-- are required engagement as part of the class but will not be used in this study without consent, as noted previously.

Confidentiality – Any information obtained in connection with this research study that can be identified with you will be disclosed only with your permission; Your results will be kept confidential by the research team. However, other members of your group or class may disclose things said in the discussion. In any written reports or publications, no one will be identified or identifiable. Generally, only group data will be presented. The exception to this is any detailed feedback from class discussion, essays or surveys. All physical records will be kept in a locked cabinet and electronic records will be password protected on a secure drive.

Questions or Concerns – If you have any questions about this project you can contact William Schell, (406) 994-5938, wschell@montana.edu or Brett Tallman, (406) 600 - 2571, brett.tallman@student.montana.edu. If you have additional questions about the rights of human subjects you can contact the Chair of the Institutional Review Board, Mark Quinn, (406) 994-4707, mquinn@montana.edu.

AUTHORIZATION: I have read the above and understand the discomforts, inconvenience and risk of this study. I, _____ *(name of subject),* agree to participate in this research. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed: _____

Investigator: Brett Tallman

Date: _____ .

APPROVED MSU IRB 2/25/2021

APPENDIX R

IRB RESEARCH CONSENT FORM

SUBJECT CONSENT FORM
FOR
PARTICIPATION IN HUMAN RESEARCH AT
MONTANA STATE UNIVERSITY

Examining Undergraduate Engineering Leadership Identity Development

Introduction – You are being asked to participate in a research study to understand how undergraduate engineering students view leadership in an engineering context. This includes how leadership is defined in engineering and how it relates to engineering identity. The study is expected to help engineering educators understand the development of engineering leadership skills and identity. The results of this study will be used to understand one educational approach to improve the development of leadership skills and identity in undergraduate engineering students. You have been asked to participate because you are an undergraduate engineering student.

Procedure - Participation is voluntary and there is no cost to you to participate. If you agree to participate you will be asked to complete one survey initially, and a second survey after the activity. In addition, your participation during the class session, including the relevant homework, will be recorded. Participation is voluntary and you can choose to not answer any survey questions you do not want to answer and/or you can stop at any time.

Risks and Benefits – While group and class instructions will be not to share anything said during group interaction and class time, there is a risk that other participants of the group or class could disclose the things that were said-- during group meetings or class-- to those who were not there. If there are questions you wish to answer in a private setting, individual discussion can be arranged. Along with the satisfaction of furthering engineering research, those who complete this study will receive one homework credit, contingent upon course instructor approval.

Decline to Participate - If you decline to participate, you may skip the surveys, and your responses as part of class activity will not be recorded. The class and group activities-- as well as relevant discussion-- are required engagement as part of the class but will not be used in this study without consent, as noted previously.

Confidentiality – Any information obtained in connection with this research study that can be identified with you will be disclosed only with your permission; Your results will be kept confidential by the research team. However, other members of your group or class may disclose things said in the discussion. In any written reports or publications, no one will be identified or identifiable. Generally, only group data will be presented. The exception to this is any detailed feedback from class discussion, essays or surveys. All physical records will be kept in a locked cabinet and electronic records will be password protected on a secure drive.

Questions or Concerns – If you have any questions about this project you can contact William Schell, (406) 994-5938, wschell@montana.edu or Brett Tallman, (406) 600 - 2571, brett.tallman@student.montana.edu. If you have additional questions about the rights of human subjects you can contact the Chair of the Institutional Review Board, Mark Quinn, (406) 994-4707, mquinn@montana.edu.

AUTHORIZATION: I have read the above and understand the discomforts, inconvenience and risk of this study. I, _____ *(name of subject),* agree to participate in this research. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed: _____

Investigator: Brett Tallman

Date: _____ .

APPENDIX S

PRE-LECTURE VIDEO TRANSCRIPTS

Relational leadership video:

Welcome to this video on relational leadership. Today, we'll explore the distinction between positional and relational views of leadership.

When I was in college, I was asked by the leaders of an organization I was part of to attend leadership training. I decided not to go, because I didn't see myself as a leader. I was an engineering student who didn't have time for additional positional responsibilities. And I didn't feel particularly inclined to learn about better ways to communicate and empathize.

Well, at the time, I also captained our intramural volleyball team. I hosted two weekly study sessions at my apartment. I helped connect 5 on-campus groups with similar shared vision. I regularly guided younger students and peers through difficult challenges or life circumstances. And, I trained and guided two other undergraduates in a research lab. And yet, I did not see myself as a leader. Was I? If so, how? And why didn't I see it that way?

Today, we'll explore the limits of positional-based views of leadership. Further, we'll outline how relational views address these limitations, and the types of behaviors and perspectives that characterize this approach to leadership. Finally, we'll explore the benefits of relational leadership and where it leads.

So, what do I even mean by positional leadership? Generally, positional leaders are obvious. They have authority. They have a title. They manage others or tell people what to do. They have the answers. We see them in store managers, CEOs, or our teachers. Many of you have probably served as positional leaders—maybe in sports, student government, or your job.

Yet this model requires that the leader has full authority, full responsibility, and the knowledge necessary to make sound judgments for the group. And this is the rub. Basically, this model breaks down when authority is not absolute or when responsibility is shared—like in a class project, where you and your peers are working together. Or, when a project is so complex, that one person simply does not have the knowledge, expertise, or time required 100% of the time—like in a diverse team of experts, which is common in industry. In these scenarios, the leader has to depend on the competence and engagement of the whole team.

In situations like these, we can introduce a more expansive view of leadership that doesn't solely rely on position or authority. In this view, leadership involves participating in a way that works towards a common purpose. Or, as defined by the literature: it is "a relational process of people together attempting to accomplish change or make a difference to benefit the common good." Komives 1998, p. 21. In this view, team members share responsibility for project success. Maybe it is through participation in conversations about the project path. Or maybe it is through technical guidance where the rest of the team is weak or untrained. Or, maybe it through the unique talents that one team member has. In the relational model, team members work inclusively with others, share perspectives and address challenges together. Of course, this approach requires trust and common vision. And, it requires working with others, which

involves interpersonal skills. But, seeing leadership within this context opens up a world of possibility, where a team can pursue goals far out of reach of any one individual, as they depend on one another. Within this context, it is easier to see that leadership may reflect dedication to and participation in the project, rather than simply authority. Hence, it is a practice that is open to all team members.

In summary, relational leadership does acknowledge the authority that comes with position. But, it proposes a more inclusive view of leadership, where team members work together towards a common goal. In highly complex projects and environments where peers are working together, a relational view of leadership provides a context for full engagement and participation by all team members. From this approach, one can see leadership happening all over in interdependent teams. Moreover, researchers report that when team members can practice leadership in this way, the entire team benefits.

So, maybe I was a leader in college, even if I shunned being called one. In retrospect, I couldn't see the value of the relational leadership that I was practicing. So, when I was invited to further training, I missed out on cultivating skills that might have helped. They might have helped me to collaborate with my lab mates or even mentor them. They might have helped me guide coordination between campus groups. And they might have helped me make study sessions more productive. In other words, the projects and individuals in which I was invested would have all benefitted.

I hope this brief discussion of relational leadership gives you insight into more expansive ways of working with others towards a shared goal, in meaningful, interdependent ways. Thank you for joining me.

Engineering leadership orientations video:

Welcome to this video on engineering leadership. Today, we'll briefly explore why engineering leadership matters, and what it looks like.

When many of us look around our community for leaders, we see certain characteristics. We might see the successful businessman single-handedly leading a giant organization, or we might hear a dynamic public figure inspire listeners, or we might envision an individual with a commanding presence and charisma to accomplish whatever is envisioned. In our personal lives, we might think of an individual in a position of authority, or a person that influences others effortlessly in social settings. And these are ways in which leadership is often expressed in broader society.

As a result, it is not uncommon for engineers—or aspiring engineers—to find these ideas uncompelling—or even abrasive. Many of us choose engineering because it is orderly. Or because of the promise the field holds to build a better world, based on applied science. Regardless of our motivation, the idea of a charismatic personality taking charge of a technical project and pushing it forward out of sheer will generally doesn't sit well with us. So, does leadership have anything to do with engineering? If so, what?

Today, we'll first address the value of leadership to engineering. From there, we'll briefly explore three orientation that characterize engineering leadership, as well as core elementary skills that contribute to their effectiveness.

First, while technical competence is essential to the engineering profession, we don't sit around calculating all day. We work with suppliers, we source components, and we create solutions to challenges. In addition, we collaborate with peers, we work with engineers in other fields, and we support others who are having difficulties. This requires the ability to work with others effectively. To take responsibility. To support your team's next project. It may also include helping new engineers and learning from the old hands. These aspects of the profession are essential to successful engineering, and they relate to what leadership actually looks like in engineering.

To provide a cohesive view of what engineering leadership looks like in industry, several scholars at university of Toronto researched engineering companies to see how professional engineers practiced leadership. They discovered that there were three common ways professionals approached engineering leadership:

The first is Technical Mastery. These are colleagues that you go to for technical guidance. They have subject-matter mastery and are adept technical problem solvers, with a long-term approach to honing their craft. These individuals influence their peers through mentorship and coaching; they can be observed helping novice engineers become more competent in the technical fields of the organization. Core elementary skills for

these leaders are teaching and mentoring other individuals, so they can learn from your expertise.

The second engineering leadership orientation is Collaborative optimization. These are peers that guide their teams and can bring out the best in everyone. They have technical competence in a number of fields, possibly in different disciplines. As a result, they often have a clear, broad view of what it takes to succeed as a team. These leaders are catalysts to group effectiveness and collaboration. They leverage team members' strengths, while also managing conflict and keeping the project moving forward. Core elementary skills for these leaders are collaboration, building teams, and empowering the team to work effectively.

The third engineering leadership orientation is Organizational Innovation. They are often visionary, entrepreneurial engineers who are able to use their own industry knowledge and creative approach to address market and organizational challenges. Their creativity and strategic insight can provide direction and vision for teams, and even the entire organization. These individuals were satisfied accomplishing an envisioned project that they could not have done on their own. Core elementary skills for these leaders are navigating organizations, understanding complex systems, big picture thinking, and creative approaches to organizational challenges.

It should also be noted that engineers sometimes expressed different leadership orientations based on their environment or season of career. Far from being 3 distinct paths, they express three core ways that professional engineers contribute to their company's mission. This may be through ensuring technical competence is brought to one aspect of a project; maybe through bringing interdisciplinary specialists together to collaborate effectively; or maybe through identifying creative applications of cutting edge technology or processes.

In summary the three orientations outlined here provide a model for how professionals exercise engineering leadership. This leadership enables individuals to meaningfully contribute to team success, take responsibility for technical accuracy, and leverage technical solutions to address big challenges. In this way, exercising leadership is an essential aspect of the professional engineer's role in an organization, and even in society.

APPENDIX T

ASSUMPTION- AND VALIDITY-FOCUSED ANALYSES

Lower-Division Demographic Impact on Outcome Variables

Leader identity, by demographic variables

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Recoded RACE	1	0.36496	0.364959	1.76	0.209
Recoded MAJOR	5	0.92503	0.185006	0.89	0.515
FEMALE	1	0.00094	0.000937	0.00	0.947
Error	12	2.48330	0.206942		
Lack-of-Fit	1	0.32572	0.325724	1.66	0.224
Pure Error	11	2.15758	0.196144		
Total	19	3.71693			

OTL-Power, by demographic variables

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Recoded RACE	1	0.1101	0.1101	0.12	0.736
Recoded MAJOR	5	5.8900	1.1780	1.27	0.337
FEMALE	1	2.7580	2.7580	2.98	0.110
Error	12	11.0942	0.9245		
Lack-of-Fit	1	0.8274	0.8274	0.89	0.367
Pure Error	11	10.2668	0.9333		
Total	19	17.7555			

OTL-Development, by demographic variables

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Recoded RACE	1	0.2385	0.2385	0.56	0.470
Recoded MAJOR	4	0.5669	0.1417	0.33	0.851
FEMALE	1	0.3491	0.3491	0.82	0.385
Error	11	4.6935	0.4267		
Lack-of-Fit	1	1.2872	1.2872	3.78	0.081
Pure Error	10	3.4063	0.3406		
Total	17	5.6007			

OTL-Shared, by demographic variables

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Recoded RACE	1	0.0112	0.01121	0.00	0.947
Recoded MAJOR	5	12.7543	2.55086	1.06	0.429
FEMALE	1	4.0393	4.03926	1.68	0.220
Error	12	28.9243	2.41036		
Lack-of-Fit	1	0.0868	0.08678	0.03	0.859
Pure Error	11	28.8375	2.62159		
Total	19	42.0000			

Engineering Leadership Relationship, by demographic variables

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Recoded RACE	1	1.3305	1.3305	0.58	0.458
Recoded MAJOR	5	3.9681	0.7936	0.35	0.874
FEMALE	1	0.1033	0.1033	0.05	0.835
Error	13	29.5890	2.2761		
Lack-of-Fit	1	1.9890	1.9890	0.86	0.371
Pure Error	12	27.6000	2.3000		
Total	20	34.6667			

Upper-Division Demographic Impact on Outcome Variables

Leader identity, by demographic variables

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Recoded MAJOR	7	4.5504	0.65006	1.08	0.394
FEMALE	1	0.0394	0.03945	0.07	0.799
Error	39	23.4695	0.60178		
Lack-of-Fit	4	2.5125	0.62813	1.05	0.396
Pure Error	35	20.9570	0.59877		
Total	47	28.1649			

OTL-Power, by demographic variables

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Recoded MAJOR	7	5.5632	0.7947	1.09	0.385
FEMALE	1	0.3101	0.3101	0.43	0.517
Error	43	31.2671	0.7271		
Lack-of-Fit	4	2.2261	0.5565	0.75	0.566
Pure Error	39	29.0410	0.7446		
Total	51	37.1377			

OTL-Development, by demographic variables

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Recoded MAJOR	7	6.1461	0.8780	1.62	0.157
FEMALE	1	0.3108	0.3108	0.57	0.453
Error	42	22.7881	0.5426		
Lack-of-Fit	4	0.6070	0.1517	0.26	0.902
Pure Error	38	22.1812	0.5837		
Total	50	29.0368			

OTL-Shared, by demographic variables

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Recoded MAJOR	7	3.6545	0.522075	0.65	0.710
FEMALE	1	0.0026	0.002630	0.00	0.955
Error	43	34.3599	0.799067		
Lack-of-Fit	4	1.7225	0.430630	0.51	0.725
Pure Error	39	32.6374	0.836855		
Total	51	38.0144			

Engineering Leadership Relationship, by demographic variables

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Recoded MAJOR	7	8.5985	1.2284	0.90	0.512
FEMALE	1	0.3210	0.3210	0.24	0.629
Error	42	57.0457	1.3582		
Lack-of-Fit	4	1.1981	0.2995	0.20	0.935
Pure Error	38	55.8476	1.4697		
Total	50	65.6863			

Lower-Division Course Impact on Outcome Variables

Leader identity, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
CLASS	2	0.1949	0.09745	0.50	0.613
Error	22	4.2912	0.19505		
Total	24	4.4861			

OTL-Power, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
CLASS	2	0.1863	0.09316	0.10	0.901
Error	24	21.4426	0.89344		
Total	26	21.6289			

OTL-Development, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
CLASS	2	0.6820	0.3410	0.98	0.392
Error	22	7.6830	0.3492		
Total	24	8.3650			

OTL-Shared, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
CLASS	2	3.960	1.980	1.12	0.343
Error	24	42.457	1.769		
Total	26	46.417			

Engineering Leadership Relationship, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
CLASS	2	0.3268	0.1634	0.09	0.912
Error	25	44.3518	1.7741		
Total	27	44.6786			

Upper-Division Course Impact on Outcome Variables

Leader identity, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
CLASS	2	0.7716	0.3858	0.67	0.517
Error	48	27.6731	0.5765		
Total	50				

OTL-Power, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
CLASS	2	0.4795	0.2397	0.31	0.734
Error	52	40.1185	0.7715		
Total	54	40.5980			

OTL-Development, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
CLASS	2	0.5467	0.2733	0.48	0.621
Error	51	29.0008	0.5686		
Total	53	29.5475			

OTL-Shared, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
CLASS	2	1.762	0.8812	1.16	0.322
Error	52	39.574	0.7610		
Total	54	41.336			

Engineering Leadership Relationship, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
CLASS	2	5.229	2.615	2.15	0.127
Error	51	62.104	1.218		
Total	53	67.333			

Completers vs. Non-completers of Retrospective Survey, High Mortality Course

Gender (Femaleness), by Completion status

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
Completion STATUS	1	0.1003	0.1003	0.33	0.565
Error	67	20.1026	0.3000		
Total	68	20.2029			

Race (Whiteness), by Completion status

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
STATUS	1	0.1799	0.17991	4.48	0.038
Error	67	2.6897	0.04014		
Total	68	2.8696			

OTL-Development, by class

Term	Df	Adj. SS	Adj. MS	F-Value	*p*-value
MAJOR	5	2.989	0.5978	2.70	0.029
Error	63	13.967	0.2217		
Total	68	16.957			

APPENDIX U

PRE-SURVEY AND RETROSPECTIVE SURVEY COMPARISON

		LOWER-DIVISION	UPPER-DIVISION
		MEAN	MEAN
LSI	PRE-SURVEY	3.881	0
	RETRO BEFORE	3.867	4.663
	RETRO NOW	4.5	3.867
OTL-Power	PRE-SURVEY	2.609	0
	RETRO BEFORE	3.531	2.609
	RETRO NOW	2.901	3.531
OTL-Development	PRE-SURVEY	3.879	0
	RETRO BEFORE	3.676	3.879
	RETRO NOW	4.195	3.676
OTL-Shared	PRE-SURVEY	4.534	0
	RETRO BEFORE	4.648	4.534
	RETRO NOW	5.926	4.648
ELR	PRE-SURVEY	5	0
	RETRO BEFORE	4.536	5
	RETRO NOW	6.143	4.536

APPENDIX V

CLASS YEAR COMPARISON ANALYSIS

Leader Identity Difference by Year

	DF	Adj SS	Adj MS	F-Value	P-Value
YEAR	1	0.3922	0.3922	0.70	0.405
Error	76	42.5837	0.5603		
Total	77	42.9760			

Leadership Construct Difference by Year, with Control Variables

OTL-Power by Year, with controls

Source	DF	Adj SS	Adj MS	F-Value	P-Value
DFOTL_I	1	8.5864	8.58642	16.26	0.000
DFOTL_S	1	1.2477	1.24772	2.36	0.130
DLXE	1	0.5525	0.55248	1.05	0.311
YEAR	1	0.1575	0.15754	0.30	0.587
POS	1	0.3825	0.38249	0.72	0.399
FEMALE	1	2.0453	2.04526	3.87	0.054
Recoded MAJOR	8	4.8176	0.60220	1.14	0.353
Error	52	27.4645	0.52816		
Lack-of-Fit	51	27.4645	0.53852	*	*
Pure Error	1	0.0000	0.00000		
Total	66	53.3546			

OTL-Development by Year, with controls

Source	DF	Adj SS	Adj MS	F-Value	P-Value
DFOTL_D	1	9.7980	9.79798	16.26	0.000
DFOTL_S	1	0.2216	0.22160	0.37	0.547
DLXE	1	0.5248	0.52482	0.87	0.355
YEAR	1	0.0143	0.01426	0.02	0.878
POS	1	0.0850	0.08497	0.14	0.709
FEMALE	1	1.1637	1.16366	1.93	0.171
Recoded MAJOR	8	3.4363	0.42954	0.71	0.679
Error	52	31.3398	0.60269		
Lack-of-Fit	51	31.3398	0.61451	*	*
Pure Error	1	0.0000	0.00000		
Total	66	54.4664			

OTL-Shared by Year, with controls

Source	DF	Adj SS	Adj MS	F-Value	P-Value
DFOTL_D	1	3.8881	3.8881	4.09	0.048
DFOTL_I	1	0.3195	0.3195	0.34	0.565
LXEPRE	1	10.0579	10.0579	10.57	0.002
YEAR	1	1.9424	1.9424	2.04	0.159
POS	1	2.8243	2.8243	2.97	0.091
FEMALE	1	0.3166	0.3166	0.33	0.567
Recoded MAJOR	8	2.0165	0.2521	0.26	0.974
Error	52	49.4778	0.9515		
Lack-of-Fit	51	47.4778	0.9309	0.47	0.851
Pure Error	1	2.0000	2.0000		
Total	66	82.4496			

Engineering Leadership Relationship by Year, with controls

Source	DF	Adj SS	Adj MS	F-Value	P-Value
DFOTL_D	1	1.2852	1.28522	1.05	0.311
DFOTL_I	1	1.0699	1.06990	0.87	0.355
DFOTL_S	1	6.4274	6.42745	5.23	0.026
YEAR	1	0.8688	0.86878	0.71	0.404
POS	1	0.3307	0.33067	0.27	0.606
FEMALE	1	0.2793	0.27929	0.23	0.636
Recoded MAJOR	8	7.3035	0.91294	0.74	0.653
Error	52	63.8902	1.22866		
Lack-of-Fit	51	63.8902	1.25275	*	*
Pure Error	1	0.0000	0.00000		
Total	66	96.5075			