Investigating Shared Leadership in Undergraduate Capstone Design Teams

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ABSTRACT (Academic)

Leadership is an area of increasing interest for the engineering profession. Strategic documents assert the need for engineers to take more prominent leadership roles to better inform complex policy decisions. Engineering leadership scholars assert, however that adequate models of how engineers lead do not exist and that traditional leadership models are contrary to the collaborative norms of engineering practice. To address this gap in engineering leadership literature, this dissertation develops a model of how engineering students lead in team-based design project environments, an example of the collaborative environment that is commonplace in engineering practice.

This quantitative study used a combination of round-robin (360-degree) survey data and course grades to examine the Full Range of Leadership within mechanical engineering-centric capstone design teams. Using a combination of cluster analyses, social network analyses, and regression analyses in a three manuscript approach, this dissertation 1) validated a Mechanical Engineering capstone version of the Full Range of Leadership, 2) determined the degree of shared leadership within the teams and how to classify teams based on their degree of shared leadership, and 3) related shared leadership to both team effectiveness and team attributes.

The study resulted in a shared leadership model for engineering design teams. The model represents leadership as a three-form, shared phenomenon within teams. The amount of leadership within the team relates positively to both the group process and satisfaction measures of team effectiveness, but not to task performance. This relationship is moderated by the distribution of leadership, indicating that a limited amount of shared leadership may be more effective. Selected team attributes are related to the degree of shared leadership within the teams. The results broaden our conceptualization of leadership beyond an individual phenomenon, making it a shared phenomenon that is an integral component of design teamwork as it relates to design team effectiveness.

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Leadership is an area of increasing interest for the engineering profession. Strategic documents assert the need for engineers to take more prominent leadership roles to better inform complex policy decisions. Engineering leadership scholars assert, however, that adequate models of how engineers lead do not exist and that traditional leadership models are contrary to the collaborative norms of engineering practice. To address this gap in engineering leadership literature, this dissertation develops a model of how engineering students lead in team-based design project environments, which is a collaborative environment that is commonplace in engineering practice.

This quantitative study used a combination of round-robin (360-degree) survey data and course grades to examine the leadership within senior-level, undergraduate mechanical engineering capstone design teams. Using a combination of analytical methods in a three manuscript approach, this dissertation 1) validated a new version of the Full Range of Leadership model for senior-level mechanical engineering students, 2) determined the degree of shared leadership within the teams and how to classify teams based on their degree of shared leadership, and 3) related shared leadership to both team effectiveness and team attributes.

The study resulted in a three-form, shared leadership model for engineering design teams. The amount of leadership within the team relates positively to a team's extra effort and team member satisfaction, but not to the team's course grades. These relationships are diminished as leadership is more distributed across team members, indicating that a limited amount of shared leadership may be more effective. Certain team attributes also relate to the degree of shared leadership within the teams. The results broaden our conceptualization of leadership beyond an individual phenomenon, making it a shared phenomenon that is an integral component of design teamwork as it relates to design team effectiveness.

Dedication

To Janet

Thank you for your loving support of my many endeavors.
Sometimes you can see me better than I can see myself.

To John and Andrew

May this dissertation be an example of what you can achieve when you believe in yourself, set goals, and work hard. Thank you for being a source of inspiration and a joy.

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To Mom and Dad, Debbie, Chris, Brad, and Emily. Thanks for your continued support through my many exciting endeavors. Not in my wildest dreams could I envision transitioning from combat in Afghanistan to getting a Ph.D. in Blacksburg, Virginia.

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Introduction

1.1 Leadership Development for Undergraduate Engineering Students

As society and technology continue to integrate across the globe, the need for engineering-minded leaders who can influence the development of sustainable, technically sound policy decisions continues to increase (National Academy of Engineering, 2004, 2005; National Research Council, 2007). The American Society for Mechanical Engineers (ASME) (2012) relays this need, emphasizing an increased sense of urgency toward developing engineers with leadership capability:

> *"Engineers must take leadership roles not only on technical projects but in society more generally. Engineers must lead in their communities, in local, state and federal governments, and help lead society to a sustainable world. There are probably no second chances, now is the time for action, and we have to get it right. Now is the time for engineering leadership, our country needs it and our planet needs it." (p. 3)*

This call to action emphasizes both the need for diverse leadership skills (encompassing both technical projects and society more generally), and their importance and urgency ("no second chances"). For the United States, developing the next generation of engineers to serve in societal leadership roles is vital to maintaining its long-term technological edge (American Society for Engineering Education, 2009, 2012; National Academy of Engineering, 2004; President's Council of Advisors on Science and Technology, 2012; STEM Development Office, 2009).

To meet this need, the National Academy of Engineering (2004) argued that undergraduate engineering programs should work to help students develop a basic level of leadership knowledge that can then be applied throughout their careers. Farr and Brazil (2009) argue that the undergraduate experience is the opportune time to teach the fundamentals of leadership for engineers. However, the engineering discipline broadly has been slow to provide an emphasis on leadership. Although the calls for leadership development have increased in sense of urgency, engineering leadership education still has not emerged as a strong area of emphasis for undergraduate engineering student development (Rottmann, Sacks, & Reeve, 2014). Rottmann et al. (2014) summarize four barriers to engineering being widely recognized as a leadership profession, which have prevented widespread acceptance and implementation of engineering leadership education: 1) traditional, hierarchical views of leadership are inconsistent with collaborative norms of engineering practice; 2) there is discomfort with the imprecise nature of leadership concepts; 3) engineering departments maintain an extracurricular orientation of leadership development that may propagate to students the notion that leadership is peripheral to the engineering curriculum; and 4) engineering career trajectories require five to ten years of technical work prior to leadership or management roles. Recent career pathway research by Kinoshita, Young, and Knight (2014), however, provides evidence that leadership knowledge may be required earlier than the five to ten years Rottmann et al. (2014) assert, as graduates may take on leadership related, engineering supervisory positions within the first three years of professional practice. My study addresses the first two barriers by investigating leadership within engineering student capstone design teams. Developing a model for how engineers lead in formative, collaborative, team-based environments will address the third barrier by providing engineering educators with a conceptualization of leadership that is not peripheral, but integral to undergraduates' engineering experiences. Understanding how engineering students lead in their capstone design experiences may also give practicing engineers a starting point by which to help newly hired engineers assimilate into career-spanning professional engineering leadership practices.

The evolution of engineering towards a leadership orientation coincides with recent and evolving shared perceptions of the leadership phenomenon itself, thus creating an opportune time for examining leadership in an engineering context. However, little is currently known regarding leadership models that are applicable to a collaborative engineering context; engineering educators and practicing engineers cannot reference an empirically tested model of how engineers lead in collaborative, team-based engineering settings (Reeve, Rottmann, & Sacks, 2015; Rottmann et al., 2014). Developing models of effective leadership may help the profession of engineering manage the transition towards an increased leadership role by making the leadership phenomenon integral to common engineering professional experiences.

One such model that has emerged in the last decade as a new conceptualization of leadership is the shared leadership paradigm (Pearce & Conger, 2003a). Pearce (2004) has described shared leadership as “a simultaneous, ongoing, mutual influence process within a team that is characterized by ‘serial emergence’ of official as well as unofficial leaders” (p. 48) within an organization. He further asserts that it may be an applicable model for knowledge work that is creative, complex, and interdependent, which coincides with the nature of team based design work as described by Newstetter (1998). The shared leadership paradigm departs from past norms where leadership was conceptualized as being individual and vertical (Jackson & Parry, 2011; Markham, 2012; Northouse, 2013; Pearce & Conger, 2003a); under these previous conceptualizations, one leader was in charge, and followers receive leadership.

Student design courses may be an applicable context in which to investigate the degree to which undergraduate engineers share leadership. Design teams are traditionally the educational settings in which leadership is incorporated most intentionally into the undergraduate engineering curriculum (Farr & Brazil, 2009; Farr, Walesh, & Forsythe, 1997). Although research is limited, studies also indicate that shared leadership may be an applicable model for the undergraduate engineering student design team context. A quantitative study by Zafft, Adams, and Matkin (2009) and qualitative work by Feister, Zoltowski, Buzzanell, Oakes, and Zhu (2014) provide indications that students share leadership within their design team experiences. Using the Competing Values Framework, Zafft et al. (2009) found that student design teams exhibit a dispersion of different leadership profiles across the team and that increased dispersion related positively to team performance in terms of course grades. Through a discursive psychological examination of engineering student interviews, Feister et al. (2014) found that students describe leadership as emergent and fluid within their design teams, often despite having appointed individual leaders. Both studies advocate a deeper examination of the degree to which leadership is currently shared among design team members and how shared leadership relates to team effectiveness and team member satisfaction with the teaming experience.

1.2 Need for this Research

The preponderance of engineering related leadership literature fails to address how engineering students lead in a collaborative, team-based engineering environment such as the undergraduate design team experience. Small sample qualitative studies have mainly addressed how students and faculty view the phenomenon of leadership within an engineering context (e.g., AlSagheer & Al-Sagheer, 2011; Cox, Cekic, & Adams, 2010; Sabatini & Knox, 1999;

Schuhmann, 2010). Other literature describes how engineering students develop as leaders along the pathway from college through professional practice (e.g., Farr & Brazil, 2009; Farr et al., 1997), class level curricula for engineering student leadership development (e.g., Bowman & Farr, 2000; Galli & Luechtefeld, 2009; Hanus & Russell, 2007; Seat, Parsons, & Poppen, 2001), and program-level curricula (e.g., Bayless, Mitchell, & Robe, 2009; Schuhmann, 2010; Williams, Ahmed, Hanson, Peffers, & Sexton, 2012). A few quantitative studies have focused on instrument development (Ahn, Cox, London, Cekic, & Zhu, 2014; Gerhart, Carpenter, Grunow, & Hayes, 2010) and predictive mathematical modeling of leader emergence (Guastello, 2011). Collectively, however, this literature fails to examine how engineering students enact leadership within their teaming experiences and how variations in leadership processes relate to different teaming outcomes.

An empirically validated model of engineering leadership within student design teams may also equip faculty to address team-related engagement issues that can be pervasive in project-based courses and result in diminished student learning. Project-based pedagogy literature illuminates challenges faced by faculty in bolstering students' continued engagement over the duration of an extended project (Blumenfeld et al., 1991; Jones, Epler, Mokri, Bryant, & Paretti, 2013). Correspondingly, capstone design faculty describe a need to maintain student involvement and thoughtfulness within capstone design courses as an important part of their role as guides or mentors (Pembridge & Paretti, 2010). When students remain engaged in the learning environment, they experience higher academic achievement (Lo, 2010; Pace, 1983). As discussed next, studies suggest that leadership can assist faculty with the challenges of maintaining student engagement, which in turn supports higher learning outcomes across team members.

In general, a large body of leadership literature indicates that leadership plays a prominent role in team effectiveness (Hill, 2013; Hoch, 2014; Salas, Stagl, Burke, & Goodwin, 2007; Stagl, Salas, & Burke, 2007; Wang, Waldman, & Zhang, 2014; Yukl, 2006), which is commonly viewed as a composite measure of team task performance, member satisfaction, and commitment Meta-analyses shows positive relationships between shared leadership and team effectiveness (e.g., Wang et al., 2014) and team performance (e.g., D'Innocenzo, Mathieu, & Kukenberger, 2014) Other research indicates relationships between shared leadership and increased team and individual learning in work teams (e.g., Liu, Hu, Li, Wang, & Lin, 2014). (Cohen, 1994; Salas et al., 2007; Wang et al., 2014). For student teams in non-engineering contexts, leadership practices shared across the team have been linked to students' extra effort and overall teamwork satisfaction (e.g., Avolio, Dong I., Murray, & Sivasubramanian, 1996). Small and Rentsch (2010) also found links between shared leadership and overall team performance for business student teams. Collectively, these studies provide indications that student leadership can increase student learning through increased engagement and overall team effectiveness. Although these positive links have been established in other contexts, the undergraduate engineering student design team context has not yet been studied.

As a result of the current gap in student design team leadership literature, faculty may fail to understand the positive role leadership practices may play in project based design pedagogy, relying more on what they *perceive* as effective rather than what research has shown to be effective. Faculty often teach in ways they are comfortable with or have experienced previously (Borrego, Froyd, Henderson, Cutler, & Prince, 2013; Duderstadt, 2010; Nespor, 1987). These practices fail to adhere to the cycle of research and practice that the American Society for Engineering Education (2009) advocate to foster incremental innovation in the engineering education process. In an effort to initiate a cycle of innovation with regards to engineering leadership, this study focused primarily on the second half of the cycle by using theory-based engineering education research to make visible the phenomenon of leadership within engineering student design teams that may help inform instructional practice for design faculty.

1.3 Purpose of the Study

The purpose of this multi-site, quantitative study was to investigate leadership processes within undergraduate mechanical engineering capstone design teams. This study investigated shared leadership using the Full Range of Leadership model (Figure 1.1) (Bass, 1985; Burns, 1978) to determine: 1) the applicability of a shared Full Range of Leadership model in describing leadership within engineering student design teams, and 2) the relationship between sharing the Full Range of Leadership and student design team effectiveness.

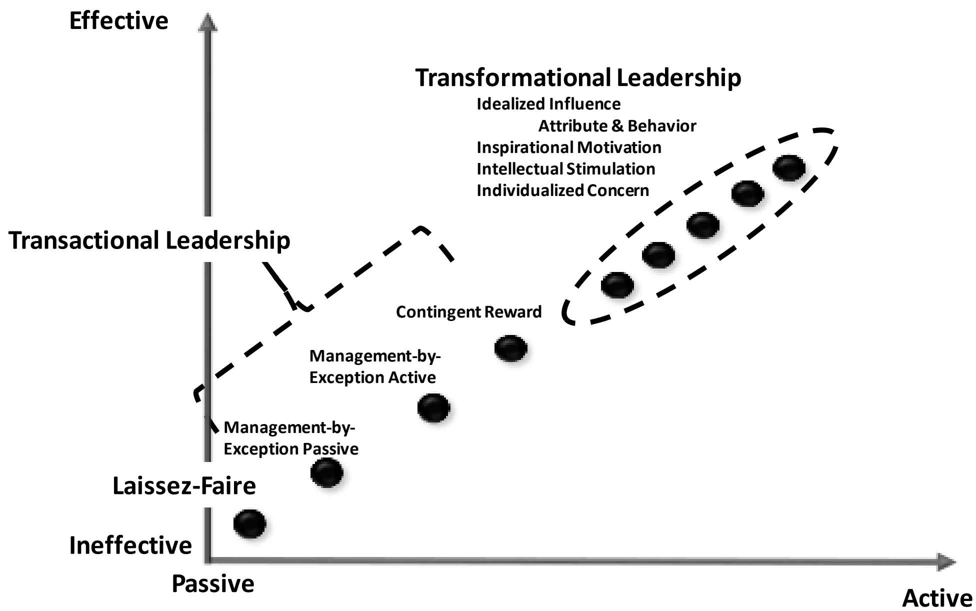

Figure 1.1. Full Range of Leadership
adapted from (Northouse, 2013, p. 192)

Using this well-established leadership model to operationalize the leadership phenomenon, this study explored engineering leadership in a new way by examining not only *how* undergraduate engineers enact leadership using the Full Range of Leadership model, but *how many* undergraduate engineers working on a collaborative team-based design project enact leadership by using a shared leadership perspective.[1] The focus was on the capstone design experience because this team learning environment requires students to practice leadership and provides creative, complex, and interdependent knowledge work (Newstetter, 1998), which may be conducive to shared leadership (Pearce, 2004). The goal of the study was to determine an effective leadership model for mechanical engineering-centric capstone design teams (i.e., majority ME students). To accomplish this goal, this study addressed a total of six research questions paired together in a three manuscript (Chapters 3-5) approach:

[1] The vast majority of the work conducted in this study is my own. I conducted all data analyses, preliminary interpretation of results, and drafting of all dissertation chapters, which constitutes authorship in accordance with the American Psychological Association (2010). The reader may note, however, that the pronoun used throughout Chapters 3, 4, and 5 is "we" instead of "I." This choice of pronouns reflects the integral role my committee chair Dr. David Knight played in the overall dissertation process. The three manuscripts included in those chapters are written in preparation for publication in the Journal for Engineering Education (JEE) or a similar research publication. Dr. Knight's role throughout the study's development is acknowledged through second authorship on the manuscripts that resulted from this dissertation. Dr. Knight was instrumental in his continued counsel, contributions to study design, proofreading, and vetting of the work I produced.

Chapter 3: Manuscript 1: The Full Range of Leadership for Engineering: Examining a subset of the Multifactor Leadership Questionnaire for mechanical engineering capstone design teams.

This study examined the validity of the Full Range of Leadership model for the undergraduate engineering capstone design context. The study confirmed an ME capstone version of the model developed with pilot data that provided the foundational understanding of different forms of leadership within the engineering design team context. This foundational understanding allowed for more complex development of the shared leadership model in Chapters 4 and 5. Analyses addressed the following research questions:

RQ3.1: To what extent do the scales that emerge from a modified Multifactor Leadership Questionnaire used to measure the Full Range of Leadership fit the undergraduate ME-centric student design team context?

RQ3.2: To what degree do the emerging leadership scales demonstrate validity by relating to other variables in expected ways?

Chapter 4: Manuscript 2: Shared Leadership in Engineering Teams: A social network analysis of mechanical engineering capstone design teams.

This second study used social network analysis to establish the extent to which the forms of leadership identified in Chapter 3 were shared among members of the design teams. The measures of shared leadership used to address the first research question were subsequently used to identify how shared leadership could be used to classify capstone design teams. This study added a *shared* leadership structure to the study of engineering design teams and addressed the following:

RQ4.1: To what degree is leadership shared within undergraduate mechanical engineering-centric capstone design teams?

RQ4.2: To what degree does the level of shared leadership classify undergraduate mechanical engineering-centric capstone design teams?

Chapter 5: Manuscript 3: Is Sharing Leadership Effective? Relating shared leadership to team effectiveness and team attributes for mechanical engineering capstone design teams.

The third study established the extent to which shared leadership may be effective for undergraduate design teams and how selected team level attributes relate to shared leadership. Analyses addresses the following research questions:

RQ5.1: How does the degree of shared leadership across the Full Range of Leadership relate to undergraduate mechanical engineering-centric capstone design team effectiveness?

RQ5.2: How do team-level attributes relate to the degree of shared leadership in undergraduate mechanical engineering-centric capstone design teams?

1.4 Methods Overview

To address these research questions, this study used a *rating the members* approach with a round-robin (360-degree) survey (Gockel & Werth, 2010; Mayo, Meindl, & Pastor, 2003) to collect leadership ratings from capstone design team members of their teammates as well as their faculty advisor. The survey also collected other team and individual attribute variables, including demographics, self-reported leadership skills, team member satisfaction with the experience, and team member effort. The survey was administered at three research sites; an in-depth description of these sites is included in Chapter 2. Individual survey item data were transformed into broader leadership scales using factor analysis, which resulted in various forms of leadership variables (Chapter 3). Through social network analysis of the leadership scales, the variables were further transformed into network-based measures that quantified the degree of sharedness across each form of leadership. Cluster analyses classified teams based on their degree of shared leadership (Chapter 4). Additional team performance data in the form of course end presentation grades and design report grades were collected from capstone course coordinators. Statistical analyses related the measures of leadership derived from the social network analysis to measures of team effectiveness (measured in terms of group process, task performance, and individual satisfaction) and team level attributes (Chapter 5). Chapter 6 synthesizes the results of Chapters 3-5 into the graphical depiction of an engineering design team leadership model that summarizes the majority of findings.

1.5 Significance of the Study

1.5.1 Implications for Research

The methods applied in this study are novel in their approach to analyzing and visualizing the phenomenon of leadership among undergraduate senior-level mechanical engineering students. No other research has applied the shared, Full Range of Leadership model within the undergraduate engineering context. Furthermore, the use of social network analysis to develop visual representations of leadership in the form of sociograms and quantification of shared leadership within design teams are unique approaches to studying leadership within engineering. The methods used in this study can be applied to other team-level outcomes such as teamwork, communication, or shared mental models. By investigating a new conceptualization of leadership, engineering education researchers may have a fresh perspective of the leadership phenomenon that more closely aligns with contemporary, scholarly leadership literature.

This new conceptualization of leadership may give engineering education researchers a more nuanced view of leadership that may be extended to the practice of engineering more broadly. The characterization of capstone design teams based on shared leadership measures examined in Chapter 4 may provide a taxonomy for describing shared leadership within student design teams, which may facilitate further leadership study. Expanding the research to include additional settings such as freshman engineering design projects and co-curricular design teams will provide greater insight into leadership processes in various undergraduate learning environments. Additionally, expanding the research across the breadth of engineering disciplines will determine applicability across the engineering field.

1.5.2 Implications for Practice

By making the phenomenon of leadership applicable to collaborative engineering environments, faculty and students may be more apt to develop leadership understanding through more informed engineering education practice. Though producing technologically adept *leaders* is a well-documented need (National Academy of Engineering, 2004; National Research Council, 2007), it still remains largely unfulfilled (Bayless & Robe, 2010; Knight & Novoselich, 2014); a lack of faculty preparedness to advise leadership development may play a role (AlSagheer & Al-Sagheer, 2011; Feister et al., 2014). Quantifying and visualizing the complex phenomenon of leadership can be transformative in leadership perceptions among engineering faculty because the often-inaccessible concept of leadership is more tangible when it is linked to quantitative results. Immediate utility of the study is a thoroughly evaluated shared leadership model for senior-level mechanical engineering design students that has been empirically related to team effectiveness measures. A new visualization of effective leadership processes at the senior mechanical engineering level may provide additional resources for faculty to increase or maintain student engagement over the course of a prolonged capstone design project, thereby increasing overall student learning.

1.6 Definitions

The following definitions are provided to orient the reader to the terminology used in this research:

Leadership: The process by which an individual influences team members towards attainment of common goals. An adaptation of the Northouse (2013) definition.

Shared Leadership: "A dynamic, interactive influence process among individuals in groups for which the objective is to lead on another to the achievement of group or organizational goals" (Pearce & Conger, 2003b, p. 1).

The Full Range of Leadership Model: A model of leadership that aggregates leadership ***factors*** into three leadership ***scales*** that represent different ***forms*** of leadership:

- **Transactional Leadership:** An exchange oriented **form** of leadership where leaders exchange rewards and promises for followers' work if performance warrants. This form of leadership includes leaders keeping followers accountable for performance and work standards (Bass, 1985).
- **Transformational Leadership:** A **form** of leadership where leaders go beyond transactional leadership relationships to be attentive to the needs of followers and helps them reach their fullest potential (Bass, 1985).
- **Laissez-faire Leadership:** A **form** of leadership representing the absence of leadership behaviors. Laissez-faire leaders take a hands-off approach to leadership, generally relinquishing their leadership responsibilities. May be interpreted as a social-loafer (Avolio, 2011).

Leadership Construct: a way people conceptualize leadership; a working, hypothetical concept of leadership, formed in people's minds.

Leadership Factor: sub-elements of the Transformational and Transactional leadership scales in the Full Range of Leadership model, consisting of multiple survey items.

Leadership Scale: the indirect measurement of a leadership construct as the aggregation of multiple survey items.

Leadership Form: a leadership construct put into practice by members of a group or team.

Team Effectiveness: The production of a desired effect by a team; the evaluation of the results of team performance. Team effectiveness is often interpreted as a multi-dimensional construct (Salas et al., 2007).

Capstone Design Course: A senior-level course that provides a culminating, hands-on, project-based experiential learning activity through which analytical knowledge gained from previous courses is joined with engineering practice (Dutson, Todd, Magleby, & Sorensen, 1997).

Course Coordinator: The primary instructor for a capstone design course. This person typically coordinates the overall capstone course effort including, syllabus development, team assignment, project assignment, and the majority of course instruction. This person may serve as a faculty advisor for one or more capstone design teams.

Mechanical Engineering-Centric Capstone Design Teams: Senior-level undergraduate mechanical engineering design teams participating in a culminating design experience prior to graduation as part of a capstone design course. The teams primarily consist of mechanical engineering students but may include a minority of engineering students from other disciplines as a part of the project.

Faculty Advisor: The senior advisor for a capstone design team, charged with guiding students toward successful completion of their assigned project. This person is most often a technical faculty member of the institution but may be a professional engineer working for an external client of the project.

Social Network Analysis: The detection and interpretation of patterns of social ties among actors of a group (Nooy, Mrvar, & Batagelj, 2011). From a shared leadership perspective, these social ties are influence relationships among actors.

Sociogram: A graphical depiction of group members and their associated social ties (Mayo et al., 2003; Nooy et al., 2011; Prell, 2012).

Network Decentralization: A measure of the degree to which all members of a social network hold an equal number of ties. From a shared leadership perspective, it measures the distribution of leadership within the group. A network with decentralization closer to zero is led by a single vertical leader, whereas a network with decentralization closer to 1 shares leadership equally across the actors in the network (Gockel & Werth, 2010).

Network Density: A ratio of how many ties exist within a network compared to how many ties could potentially exist within the network. From a shared leadership perspective, it measures the amount of leadership happening within a group (Gockel & Werth, 2010).

OLS Regression: A classical model of multiple regression where the dependent variable can be explained by a linear combination of the explanatory variables and a random residual (Snijders & Bosker, 2012).

Hierarchical Linear Modeling: An extension of multiple linear regression techniques that allows for nested random coefficients (Snijders & Bosker, 2012). For example, allowing regression coefficients and intercepts to vary across research sites.

Bootstrapping: A resampling technique that generates multiple unique datasets from the original data using sampling with replacement (Field, Miles, & Field, 2012; Keith, 2006).

Chapter 2

Research Site Comparison

2.1 Population and Sample Justification

The target population for the study was undergraduate engineering students enrolled in senior-level mechanical engineering design courses that use a team-based approach. The senior level design team context, relative to the first year design team context, was an appropriate curricular setting for this investigation because shared leadership is more likely to develop in teams comprised of individuals with a high degree of expertise in their given field (Pearce, 2004). Senior level design students may not be expert engineers, but they will have reached the maximum level of training they will receive during their undergraduate tenures. Correspondingly, they may have a greater propensity to adopt some form of shared leadership in their teamwork than first-year students. The study was bounded to the mechanical engineering discipline for multiple reasons: 1) the discipline's interest in engineering leadership (see ASME Center for Education, 2011), 2) mechanical engineering's status as the largest discipline for bachelor degree attainment (Yoder, 2014), 3) access to design teams for data collection, and 4) professional interest and expertise of the researcher.

2.2 Site Selection and Demographics

This study targeted mechanical engineering capstone design courses at three institutions during the 2014–2015 academic year (Table 2.1). These institutions were purposefully chosen because of their historic leadership focus and ABET accredited engineering programs. The mixture of civilian and military institutions provided a combination of a more traditional civilian undergraduate engineering experience at site A, which may include voluntary affiliation with purposeful leadership development through the Corps of Cadets for some students or various other leadership development programs, and mandatory, 4-year leadership programs at the two military institutions (sites B and C). The AY 2014–2015 enrollments provided roughly comparable samples of civilian and military students with 342 students at site A comprising 43 teams and 287 students at sites B and C combined representing 56 teams. Table 2.1 demonstrates that the student demographics of the three institutions do not reflect national mechanical engineering bachelor degree demographics, which was a limitation of this study. Access, however, was a major consideration in the selection of the study sites; professional network contacts and proximity facilitated access to student design teams, which was necessary for data collection.

Table 2.1: Research Site Demographic Comparison

	2014 Data†											AY 2014-2015††			
Site	2014 ME Bachelor's Degree Awarded	Black	Asian	Hispanic	Native American	Pacific Islander	White	Race Not-reported	Inter-national	Male	Female	2014-2015 Enrollment	# Teams	Avg. Team Size	% Externally Sponsored Teams
Site A	320	1.3%	6.3%	4.7%	0.0%	0.0%	75.9%	0.0%	7.2%	91.9%	8.1%	342	43	9	56%
Site B	90	3.3%	4.4%	11.1%	2.2%	0.0%	73.3%	0.0%	2.2%	92.2%	7.8%	137	27	5	100%
Site C	88	1.1%	3.4%	4.5%	0.0%	0.0%	85.2%	0.0%	1.1%	86.4%	13.6%	150	29	5	41%
National	25042	2.4%	7.8%	8.5%	0.3%	0.2%	63.9%	0.0%	6.2%	87.2%	12.8%	N/A	N/A	N/A	N/A

†Data from (Yoder, 2014).
††Data collected from Course Coordinators for AY 2014–2015.

2.3 Capstone Design Course Comparison

Each of the proposed research sites offered similar capstone design experiences for students. At all three sites, the senior capstone design course is a required, year-long, two-course design experience. To understand similarities and differences across research sites and provide context for the study, a review of course materials was conducted, specifically investigating course objectives, student familiarity with the design process, course content, project selection, and team formation processes.

The objectives of each course focused primarily on the application of the engineering design process towards the development of a workable prototype (see Table 2.2 for a comparison of course objectives across the three sites). In addition to emphasis on applying the design process, each course also incorporated objectives related to professional skills, such as teamwork and communication. The course syllabi comparison shown in Table 2.2 indicated that the majority of course objective topics were common across the three sites. Each site specified between one and three additional course objectives specific to only that research site. Across these site-specific course objectives, none directly related to leadership or the teaming process, thus minimizing potential impact on the study of leadership across the sites.

Table 2.2: Course Objective Comparison

Course Objective	Site A	Site B	Site C
Design and build a mechanical and/or thermal system	✓	✓	✓
Apply the engineering design process	✓	✓	✓
Apply knowledge of math, science, and engineering to support the design process	✓	✓	✓
Define customer requirements and develop engineering specifications	✓	✓	✓
Generate multiple design concepts and down-select	✓	✓	✓
Understand team dynamics applied to engineering product development	✓	✓	✓
Understand engineering ethical responsibilities	✓	✓	✓
Communicate technical information effectively	✓	✓	✓
Apply risk management tools and/or failure mode analyses	✓	✓	
Select appropriate materials and processing techniques	✓	✓	
Conduct feasibility assessment	✓		
Generate and protect intellectual property	✓		
Incorporate societal considerations into the design process		✓	
Use project management tools to plan and track the project			✓
Use computer aided techniques to analyzed and document design details			✓
Understand the role of engineering codes and standards			✓

One major difference between the research sites was the point at which students begin work on their design projects (Table 2.3). Sites A and C followed a "class and project in parallel" instructional approach as described by Howe and Wilbarger (2006, p. 6), where course meetings were incorporated into the early part of the fall semester to relay course content in parallel with student work on their design projects. Site B used a "class then project approach" (Howe & Wilbarger, 2006, p. 6) as content-related class meetings were followed by project work beginning in lesson 10. At sites A and C, project work began during the second class meeting. In contrast, project work at site B was delayed for 10 lesson meetings to allow for an introduction the engineering design process.

These timing differences corresponded to prior instruction of the design process in the curriculum. At site A, students were first formally introduced to the engineering design process during their first-year, two-semester, general engineering course sequence. Site B students, in contrast, only received formal instruction of the engineering design process during the capstone experience. At site C, students were introduced to the engineering design process during their introduction to mechanical engineering course in their second year. These differences may have had a potential effect on the study; students at Site B had less overall time to develop teaming relationships during their project work because project assignment and corresponding team formation did not begin until lesson 10. This potential difference was somewhat mitigated, however, by the number of formal course meetings dedicated to course content facilitated by the course coordinator as opposed to team working meetings run by the student teams. Sites A and C both used 50% (i.e., 15 of 30 and 17 of 34, respectively) of their course meetings for course coordinator facilitated lecture periods. Site B, in contrast, used only 12.5% of their meeting (i.e., 10 of 80) for course coordinator facilitated lectures. In these first 10 lessons, the site B students applied the engineering design process they were learning to a small, individual project (e.g., a class ring storage box) and had not yet been formally assigned their capstone project. The other 70 course meetings were reserved for scheduled team working sessions.

Table 2.3: Site difference in course meeting useage

	Site A	**Site B**	**Site C**
Design Project Start	Lesson 2	Lesson 11	Lesson 2
First instruction of the Engineering Design Process	First-year Eng. Course	Senior Capstone Design	Second-year intro to ME course
Formal course meetings facilitated by course coordinator	15	10	17
Scheduled student team facilitated working meetings	15	70	17

Despite these differences in the timing of engineering design in the curriculum, course content was largely similar across the sites. Course meeting foci at all sites encompassed topics including facets of the engineering design process, project management, and engineering ethics, as well as various design related topics (see Table 2.4 for site-specific detail). Site A was the only site that included content that specifically focused on team leadership. This session was led by the author at the request of the course coordinator. The class meeting consisted of a 30-minute overview of leadership related principles and discussion of effective team leadership practices. The concept of shared leadership comprised less than 5% of the lecture content. As the only formal instruction on leadership included in the course, that single session was not expected to influence study results.

Table 2.4: Formal Course Meeting Topics by Site

Site A
1. Course Policy, overview of course, lab safety 2. Customer Needs, Engineering Requirements, Target Specs 3. Concept Generation and Prototyping 4. Concept Selection 5. Midterm Presentations and Report Format 6. Shared Leadership 7. Failure Mode Effects and Analysis (FMEA) 8.What is Industrial Design 9. DFM, DFA, DFDN, Risk Assessments, Codes and Standards 10. Engineering Econ and Quality 11. Systems Engineering 12. Ethics/ Case Studies in Engineering Failure 13. Case Studies in Design I 14. Case Studies in Design II 15. Wrap Up
Site B
1. Introduction to Design 2. Problem Definition I, Identifying Need, Info Gathering 3. Problem Definition II: Customer Requirement, Design Objectives 4. Problem Definition III: Benchmarking, QFD, Engineering Specifications 5. Concept Generation I: Brainstorming/Functional Decomposition 6. Concept Generation II: Morphological Charts and Alternative Generation 7. Product Realization 8. Project Management/Product Communication 9. Capstone Requirements, Workshop Orientation 10. Design Seminar (Guest Lecture)
Site C
1. Course Admin, Problem Definition 2. Quality Function Deployment 3. Project Management 4. Design Concept Generation and Engineering Models 5. Decision Making and Concept Selection 6. Embodiment Design I 7. Embodiment Design II 8. Prototype Test Plan and Risk Assessment 9. Engineering Ethics I 10. Engineering Ethics II 11. Welcome Back and Course Admin 12-17. Guest Lecture (x5 in spring semester)

Each research site required students to work in a team with peers to design, fabricate, and demonstrate a solution to a specified design problem. At all three sites, design projects were generated through a combination of sources both internal and external to the institution; the externally generated projects were vetted and scoped by course coordinators before being included in the course (see Table 1 for the percentage breakdown). Projects varied greatly and may include industry, military, assistive technology, or collegiate design competition related topics. Developing some form of working prototype was a requirement at all three sites.

Team formation processes across sites were similar as well. Teams were formed through a combination of member preference and faculty assignment. At all sites, students were given the opportunity to choose projects of interest from the list of projects available and accompanying project descriptions. At sites A and C, this process occurred within the first week of the semester. At site B, this process occurred during the first 10 lessons of the course while the students are learning the design process. Faculty assigned students to teams based on a combination of student preference for teammates as well as project topics; faculty also consider equality of capability across teams. The measure of equal capability varied across sites but generally focused on students' academic performance within the program, including engineering course performance and any prior experience with the project through undergraduate research, club participation, or internship opportunities. The size of teams varied based on the number of projects available for that academic year, complexity and scope of each project, and overall enrollment for the capstone course, with a mean team size of between 5 and 9 students across the sites (Table 2.1).

All three courses required student teams to develop team charters to assist in the formation of the team (Table 2.5). Sites A and B both required some specification of leadership structures, although these two sites did not specifically require an individual team member to be designated "team leader" as a part of their leadership structure. Site A, however, did require the specification of two team positions: 1) Team Facilitator, who provides overall coordination of team efforts and ensures all team members are held accountable for his or her individual responsibilities; and 2) Finance Manager, who monitors team financial expenditures and project funding. Although not specified as a part of the team charter, site C provided the most guidance requiring team member positions. In the site C published project guidance, teams were required to specify the following team roles among their team members: 1) Team Leader, 2) Design

Communication Editor, 3) Purchaser, 4) Technical Support Detachment Liaison, and 5) Safety Officer. The specification of team roles at sites A and C had the potential to influence team member perceptions of team leadership as an individual responsibility. Assigning roles to individuals may attribute legitimate social power to the individuals (French & Raven, 1959; Pierro, Raven, Amato, & Bélanger, 2013), which may have played a role in their ability to influence other team members (Burns, 1978; Pierro et al., 2013). Recognizing these potential effects, Chapters 3, 4, and 5 addresses specific steps used to mitigate variation across research sites when possible.

Table 2.5: Team Charter Topic Comparison

	Site A	**Site B**	**Site C**
Team Name and Logo	✓	✓	✓
Problem/Mission Statement	✓	✓	✓
Group Structure/Leadership Plan	✓	✓	✓
Decision Making/Conflict Resolution Plan	✓	✓	✓
Team Goals		✓	✓
Member Learning Goals			✓
Member and Faculty Information		✓	✓
Team Member Strengths and Weaknesses		✓	✓
Team Conduct Ground Rules/Agreements	✓	✓	✓
Team Meeting Plan	✓	✓	✓
Charter Change Procedures	✓		

In summary, this comparison of research sites indicated that there was a great deal of commonality to the students' capstone design experiences across the research sites. This commonality of experience provided preliminary indications that teams could be analyzed across sites as part of one sample, although steps were followed in analyses to test this assumption.

Chapter 3

Manuscript 1: The Full Range of Leadership for Engineering: Examining a subset of the Multifactor Leadership Questionnaire for mechanical engineering capstone design teams.

3.1 Abstract

Background

Multiple national-level reports have indicated the need for engineers to take more prominent leadership roles in the community and society to better-inform complex policy decisions. Engineering faculty are tasked to develop a basic level of leadership knowledge within undergraduate engineering students that can then be applied increasingly throughout their careers. To date, these aspirations have gone largely unfilled due at least partially to perceptions of leadership within practicing engineers that are abstract and at odds with their professional practice.

Purpose/Hypothesis

The purpose of this study is to empirically validate the well-established Full Range of Leadership model in the engineering student design team context. The results provide engineering faculty a more precise and nuanced leadership model for leadership within student capstone design teams. This research is intended to dismantle abstract views of leadership and align leadership practices with the collaborative environment engineers routinely experience.

Design/Methods

This quantitative study reviews and builds upon pilot exploratory factor analysis of the Multifactor Leadership Questionnaire with confirmatory factor analysis of a subset of items. The confirmed leadership scales are related to other related variables through correlation and analysis of variance to add additional evidence of validity to the model. The work establishes a leadership model for undergraduate, senior-level mechanical engineering-centric capstone design teams.

Results

The confirmatory factor analysis results indicate that The Full Range of Leadership is practiced by mechanical engineering-centric capstone design team members in three forms: Transformational/Contingent Reward, Active Management by Exception, and Passive-Avoidant. These three constructs are conceptually similar but distinct from the Transformational, Transactional, and Laissez-Faire constructs of the Full Range of Leadership model. The resulting leadership scales show evidence of validity within the mechanical engineering-centric capstone design context by relating in anticipated ways with self-reported leadership skills, member effort, and engineering GPA.

Conclusions

Results from this study indicate that a three-scale version of the Full Range of Leadership model is valid for team members of mechanical engineering-centric capstone design courses. By distilling leadership within the teams into three tangible and interpretable constructs, this study takes a crucial first step toward making The Full Range of Leadership relevant and approachable for engineering students preparing for professional practice.

Key Words

Engineering Leadership, Full Range of Leadership Model, Multi-Factor Leadership Questionnaire, Factor Analysis

3.2 Introduction

This research investigates the applicability of a widely recognized leadership model in the collaborative, team-based environment that engineers routinely experience. Specifically, this study explores the Full Range of Leadership model, which describes the interplay between multiple forms of leadership to garner organizational performance beyond expectations (Antonakis, Avolio, & Sivasubramaniam, 2003; Northouse, 2013; Wang, Oh, Courtright, & Colbert, 2011). This model has been recommended for use by practicing engineers (e.g., Breaux, 2006) but currently has only recently been examined in a undergraduate engineering context (e.g., Novoselich & Knight, 2015). Using a subset of the well-established Multifactor Leadership Questionnaire (Bass & Avolio, 2013) to garner leadership ratings among engineering capstone design team members, this study examines the applicability of the leadership model for interpretation in a collaborative engineering undergraduate course environment. By empirically validating the Full Range of Leadership model in the engineering student design team context, this work may give engineering faculty a more precise and nuanced way to access, understand, and teach leadership to their students. This chapter addresses the following research questions:

RQ1: To what extent do the scales that emerge from a modified Multifactor Leadership Questionnaire used to measure the Full Range of Leadership fit the undergraduate ME-centric student design team context?

RQ2: To what degree do the emerging leadership scales demonstrate validity by relating to other variables in expected ways?

3.3 Leadership Theory and Review of the Literature

The preponderance of engineering related leadership literature fails to address how leadership is enacted by students within the design team experience. Small sample qualitative studies have mainly addressed how students, faculty, and practicing engineers view leadership within an engineering context (e.g., AlSagheer & Al-Sagheer, 2011; Cox et al., 2010; Rottmann et al., 2014; Sabatini & Knox, 1999; Schuhmann, 2010). Other literature describes how engineering students develop as leaders along the pathway from college through professional practice (e.g., Farr & Brazil, 2009; Farr et al., 1997), class level curricula (e.g., Bowman & Farr, 2000; Galli & Luechtefeld, 2009; Hanus & Russell, 2007; Seat et al., 2001), and program-level curricula (e.g., Bayless et al., 2009; Schuhmann, 2010; Williams et al., 2012) for engineering student leadership development. A limited number of quantitative studies have focused on instrument development (e.g., Ahn et al., 2014; Gerhart et al., 2010), but these instruments are largely untested and lack a wide body of empirical examination.

3.3.1 The Full Range of Leadership

The Full Range of Leadership model (see Bass, 1985; Bass & Avolio, 1994) is a well-established leadership framework involving transformational and transactional leadership (Mathieu, Neumann, Babiak, & Hare, 2015). Transformational leaders focus on the change or transformation of people. According to this perspective, leaders concern themselves with, “emotions, values, ethics, standards, and long-term goals” (Northouse, 2013, p. 185). In working with followers, leaders take a more holistic role in their interactions, attending to, for example, personal needs and examining motives. Transactional leadership provides the base of leadership to achieve organizational outcomes at expectations (Bass, 1985). Transactional leadership is described as the exchange of valued outcomes between leaders and followers (Kuhnert & Lewis, 1987), i.e., special recognition for adequately completing a complex task. Transformational behaviors augment transactional behaviors to enable group outcomes to exceed expectations (Bass, 1985; Kuhnert & Lewis, 1987; Northouse, 2013). Laissez-faire is the third form of leadership accounted for in the model, describing leaders who fail to provide influence to an organization, especially when needed (Avolio, 2011; Bass, 1985).

Recent literature (e.g., Breaux, 2006; Rottmann et al., 2014) has shown links between engineering practice and the Full Range of Leadership model. Breaux (2006), for example, describes transformational leadership as an effective model for practicing engineers, as engineering leaders can champion the vision of an organization while also assisting followers in navigating engineering's dynamic, changing technical environment. In their grounded theory based examination of leadership for practicing engineers, Rottmann et al. (2014) develop a collaborative optimization leadership orientation. The authors tie this leadership orientation back to a combination of transformational and transactional leadership (Bass, 1985; Burns, 1978) as well as distributed leadership (Gronn, 2008). Similar to Breaux's (2006) description, Rottmann et al. (2014) describe how these engineering leaders facilitate group processes which can be facilitated by the relational aspects of transformational leadership. Rottmann et al. (2014) further describe how the specialized training aspects of transactional leadership may assist collaborative optimization type engineering leaders leverage and acknowledge team members' strengths. These examples of how aspects of transformational and transactional leadership play a role in the actions of engineering leaders in professional practice demonstrate the potential for these forms of leadership to represent how engineering students lead in their final stages of professional development.

3.3.2 Measuring the Full Range of Leadership

The Full Range of Leadership has been routinely measured for more than a decade using the Multifactor Leadership Questionnaire (MLQ) (Avolio, Bass, & Jung, 1999), the most prolific measure of the Full Range of Leadership currently in use (Jackson & Parry, 2011; Northouse, 2013). The full MLQ has demonstrated adequate construct validity in both individual and shared transformational leadership research (Avolio, Sivasubramaniam, Murry, Jung, & Garger, 2003). In addition, the MLQ has been validated across a wide range of contexts, including U.S. and international undergraduate and graduate business students, the U.S. military, research facilities, professional settings, and project based professional environments (Antonakis et al., 2003; Avolio et al., 1999;

Avolio et al., 2003; Keegan & Den Hartog, 2004). This study adds to this list of contexts by investigating the model in the undergraduate engineering context.

Relevant to this study, the full MLQ survey consists of 36 descriptive leadership statements that are divided among distinct leadership factors (Antonakis et al., 2003). These factors are the building blocks of the transactional, transformational, and laissez-faire leadership scales shown in the Full Range of Leadership model (Figure 3.1).

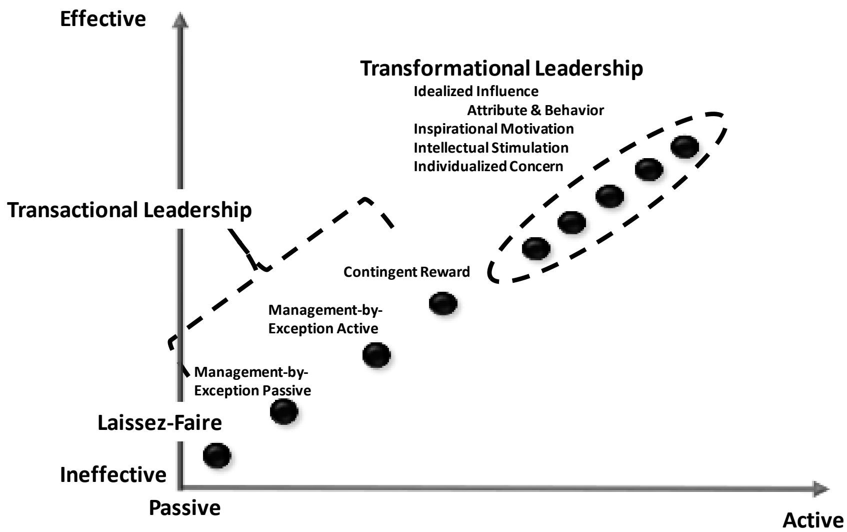

Figure 3.1. Full Range of Leadership
adapted from (Northouse, 2013, p. 192)

As noted, the transactional factors (see Table 3.1) are considered by some to be the managerial aspect of leadership, and displaying these three sets of leader actions can help a group perform at expectations (Bass, 1985; Kuhnert & Lewis, 1987; Northouse, 2013). Although transactional leadership is consistently described with all three factors (Antonakis & House, 2013; Northouse, 2013), other interpretations support a reduced scale that incorporates only active management by exception and contingent reward (e.g., Avolio et al., 1999; Bass & Avolio, 2015). At the factor level, contingent reward is a consistent positive predictor of effectiveness, active management by exception has shown mixed results, and passive management by exception has shown consistently negative relationships with effectiveness (Antonakis & House, 2013).

Table 3.1: Transactional Leadership Factors (Antonakis et al., 2003)

Factor	**Description**	**Example**
Management by Exception (Active)	Active, corrective transactions	Maintaining standards
Management by Exception (Passive)	Passive corrective transactions	Correcting mistakes
Contingent Reward	Constructive transactions	Rewarding performance, clarifying roles

Bass (1985) describes transactional leadership as a necessary pre-requisite to effective leadership, allowing for adequate group performance. To exceed expectations, however, leaders must add transformational behaviors to their repertoire (Antonakis & House, 2013; Bass, 1985, 1997; Northouse, 2013); this transformational scale, in its entirety, is a consistent positive predictor of effectiveness (Antonakis & House, 2013). As a result, the component factors are most often examined as the complete scale, contrary to the factors of transactional leadership. Transformational leadership behaviors are broken down into five factors in the MLQ (see Table 3.2).

Table 3.2: Transformational Leadership Factors (Antonakis et al., 2003).

Factor	**Description**	**Example**
Idealized Influence (Attributed)	Perception of confidence and power by others	Perceived as focusing in ideals and ethics
Idealized Influence (Behavior)	Charismatic actions of a leader	Actions centered in values, beliefs and sense of mission
Inspirational Motivation	Energizing followers	Projecting vision and optimism
Individualized Concern	Developing followers	Attending to needs
Intellectual Stimulation	Encourages innovative thinking	Challenging the status quo

The third construct of the model is laissez-faire, a measure of non-leadership or absentee leaders (Antonakis & House, 2013; Bass & Avolio, 1994). This construct negatively relates to effectiveness (Antonakis & House, 2013; Bass, 1997). Although the Full Range of Leadership model is described with laissez-faire as a separate scale (e.g., Antonakis & House, 2013; Northouse, 2013), multiple interpretations have combined this laissez-faire scale with the passive management by exception factor (from transactional leadership) into a higher order passive-avoidant scale because both negatively relate to team effectiveness (Avolio et al., 1999; Bass & Avolio, 2015).

3.3.3 Validating The Full Range of Leadership for Engineering Design Teams

In a preliminary effort to explore the Full Range of Leadership model for engineering design teams, Novoselich and Knight (2015) conducted exploratory analysis of the 36 leadership descriptive statements within the full MLQ that identified a subset of 14 leadership statements for use in leadership network studies in the engineering design team context. For that pilot study, Novoselich and Knight (2015) analyzed 435 student round-robin responses to the full MLQ collected during the 2013-2014 academic year from a large, Mid-Atlantic land grant institution and a small, northeastern military academy. In that exploratory factor analysis, the factors of the Full Range of Leadership model did not emerge as factors, thereby representing an inconsistent result with original studies that developed the model (e.g., Avolio et al., 1999; Bass, 1985). . Exploratory factor analysis of the 36 MLQ leadership items pointed to a three-construct leadership model for ME Capstone design teams, consisting of *Transformational/Contingent Reward (TCR)* [2], *Active Management by Exception (MEA)*, and *Passive-Avoidant(PA)*[3] leadership scales. These constructs are conceptually similar to but distinct from the transformational, transactional, and laissez-faire constructs contained in the Full Range of Leadership model. Because survey fatigue became an issue in pilot data collection, that

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[2] The original exploratory analysis in Novoselich and Knight (2015) labeled this construct *developing*. Further professional collaboration illuminated potential miss-interpretations of the construct's meaning because of its label. This construct was re-named transformational/contingent reward.

[3] The original exploratory analysis in Novoselich and Knight (2015) labeled this construct *passive-avoidant/laissez-faire*. Further review of current literature (Avolio et al., 1999; Bass & Avolio, 2015) indicates that a *passive-avoidant* label has been used in the literature and was re-named as such.

preliminary work empirically reduced the length of the survey to increase complete survey response rates; the analysis identified a 14-item subset of the full MLQ that adequately represented the three-scale leadership model, which was adopted for use in the present study. Although main findings from that pilot study are summarized in Appendix A, a full description can be found in Novoselich and Knight (2015).

Because of the novel findings of Novoselich and Knight (2015), additional validation of the three construct model is warranted. Although the MLQ has undergone rigorous testing in multiple contexts, Douglas and Purzer (2015) assert that peer-reviewed publication does not assure instrument quality and functionality in a new context. In addition to being administered in a novel engineering student design team context, Novoselich & Knight's (2015) recommendation to reduce the number of survey items requires a re-examination of the survey's validity for interpretation (American Educational Research Association [AERA], American Psychological Association [APA], & National Council on Measurement in Education [NCME], 2014; Douglas & Purzer, 2015; Goodwin, 2003). The copyright holder for the MLQ similarly asserts that administering only part of the survey may change the instrument's validity properties (Mind Garden, 2015); therefore, additional work must be done to demonstrate validity of the three leadership constructs, which is the goal for the present study.

Multiple sources of evidence may be used to demonstrate the validity of an instrument, as summarized in Table 3.3 (AERA, APA, & NCME, 2014; Goodwin, 2003). The survey item reduction method in Novoselich and Knight (2015) demonstrates evidence of *test content* through a purposeful item reduction strategy that ensured coverage of the three leadership constructs (with appropriate reliability and preliminary evidence of internal structure). The present study focuses on strengthening *internal structure evidence* (research question 1) and determining *relations to other variables* (research question 2) to demonstrate more fully the validity of the 14 item subset of the MLQ in the engineering student design context. Evidence of *response process* was not considered in this study because of the long history and extensive validation of the MLQ items. The questions indirectly measure leadership constructs but allow the participant to rate observable behaviors, lessening the interpretation required to rate an individual (Singleton & Straits, 2010).

Table 3.3: Summary of Validity Evidence (AERA, APA, & NCME, 2014; Goodwin, 2003)

Evidence Based on…	Description
Test Content	The relationship between the themes, wording, and format of items, tasks, or questions and the construct it intends to measure.
Internal Structure	How instrument components conform to the construct on which they are based.
Relations to Other Variables	The degree to which instrument scores are related to hypothetically similar constructs, criteria they are intended to predict, or group difference supported by theory.
Response Processes	Fit between the construct measured and the nature of the performance or response actually engaged by the participant.

The sections that follow establish anticipated relationships between the leadership scales and other measured variables in the study. The literature provides indications that measures of students' self-reported leadership skills, member effort, and engineering GPA are hypothesized to relate to the leadership that students enact as a part of their teaming experience, which should be observable in the leadership ratings collected via the reduced MLQ.

3.3.3.1 Self-Reported Leadership Skills

Establishing a relationship between the leadership scales measured by the instrument (i.e., the 14-item MLQ, which consists of teammates' external ratings of an individual) and another measure of student leadership (i.e., a self-report *leadership skills* scale) provides convergent evidence of validity (American Educational Research Association et al., 2014; Goodwin, 2003). Similar methods of comparing self and peer leadership evaluations (e.g., Goldring, Cravens, Porter, Murphy, & Elliott, 2015; McEnery & Blanchard, 1999) and personality inventories (e.g., Muck, Hell, & Gosling, 2007) have been used to determine convergent evidence of validity. For leadership specifically, Conway and Huffcutt (1997) showed weak but positive correlations between peer and self-reports of leader performance in their meta-analysis of self-peer performance ratings. As active forms of leadership (i.e., leaders enact leadership skills), TCR and MEA leadership scale values should be higher for students with higher self-ratings of leadership skills. Conversely, for an absence of leadership (i.e., PA) values should decrease with higher self-rated leadership skills. Thus, to demonstrate validity, we hypothesize:

Hypothesis 1: A self-report measure of leadership skills positively correlates with both the peer-rated TCR and MEA leadership scales and negatively correlates with the peer-rated PA scale.

3.3.3.2 Self-Reported Member Effort

Leaders are often recognized for (Hogan & Kaiser, 2005) and set an example of hard work (Avolio, Waldman, & Yammarino, 1991). Manager effort has been shown to exhibit positive relationships with member perceptions of relationship quality in studies of leader-member exchange theory (LMX) (e.g., Maslyn & Uhl-Bien, 2001). Consequently, we hypothesize the following:

Hypothesis 2: TCR and MEA Leadership scales positively correlate with a self-report scale of member effort, and PA negatively correlate with a self-report scale of member effort.

Demonstrating weaker relationships between the external ratings of students' leadership and different, but related constructs (e.g., member effort) would demonstrate discriminant evidence because those scales are meant to measure different constructs (American Educational Research Association et al., 2014; Goodwin, 2003). Because member effort is related to, but distinct from leadership itself, we anticipate smaller correlation magnitudes than those observed between the TCR, MEA, PA, and a self-reported engineering leadership skills:

Hypothesis 3: Correlation coefficients between self-reported member effort and the TCR, MEA, and PA leadership scales will have a lower magnitude than correlation coefficients between the self-reported leadership scale and the TCR, MEA, and PA scales.

3.3.3.3 Self-Reported Engineering Course GPA

Identifying differences in leadership by different groupings of students may provide additional evidence of validity, as group comparisons are often used in validation studies to demonstrate expected differences across groups (Goodwin, 2003). Leadership differences are expected to exist among students who perform differently academically because leadership involves a person's ability to influence other members of a group; expert power is an important component of the influence process (Northouse, 2013). Students who have higher grade point averages in engineering- and science-related courses may possess a source of power with which to influence their peers and hence exercise leadership. Expert power is attributed by followers to an individual who exhibits competence in a subject area (French & Raven, 1959; Pierro et al., 2013). Tonso (2007) echoes this interpretation in her ethnographic study of student design teams, demonstrating that students with high academic-science expertise (as indicated by engineering-science course performance) were afforded additional agency over their less engineering-science expert peers. The additional agency afforded to students with higher GPA would facilitate active influence within their design teams, increasing both TCR and MEA leadership and correspondingly decreasing the absentee PA leadership behaviors:

> *Hypothesis 4: Students with higher self-reported engineering course GPA have higher peer-ratings on both TCR and MEA leadership scales and lower ratings on the PA leadership scale.*

3.4 Data and Methods

3.4.1 Data Collection

Because an end goal of this study was to set conditions for measuring the Full Range of Leadership from a shared leadership perspective in follow-on research, data collection required a modified, round-robin (360-degree) version of the MLQ. The instrument was adapted following the research design proposed by Mayo et al. (2003) and consistent with the format used by Novoselich and Knight (2015). Team members assessed each of their teammates' leadership behaviors based on the 14 descriptive leadership statements (the reduced MLQ) (see Figure 3.2). The study did not require faculty advisors to reciprocally rate team member leadership in an effort to maximize full-team response to data collection. Interactions with various course coordinators and faculty advisors indicated the potential for low faculty member response rates; full team responses were required to generate team level ratings of each team member and for follow-on analysis of shared leadership.

Not at all--- Once in a while---Sometimes---Fairly Often---Frequently, if not always
1 2 3 4 5

	Member 1	Member 2	Member 3	Member 4	Member 5	Faculty 1	Faculty 2
1. Provides [redacted] for my efforts							

Figure 3.2. Sample Round-Robin Survey Item
(Question redacted due to copyright agreements)

Participants were enrolled in year-long (2014–2015), team-based, mechanical engineering-centric, senior level capstone design courses at three institutions: a large, mid-Atlantic research university (site A) and two smaller engineering-focused military institutions (sites B and C). These study sites were purposefully chosen because of their historic leadership focus, ABET accredited engineering programs, comparable capstone design experiences, and access to participants. Qualitative comparison of course syllabi and team charter requirements across the three institutions indicated similarity in the capstone design experience with regard to course objectives, course content, project requirements, and team-based pedagogy (see Chapter 2). The mixture of civilian and military institutions provides a combination of a more traditional undergraduate engineering experience at site A and a mandatory, 4-year leadership experience at sites B and C. Mechanical engineering was specifically chosen because of professional interest in engineering leadership as demonstrated by the ASME, mechanical engineering's prominence as the largest discipline for bachelor's degree attainment (Yoder, 2014), and alignment with the researcher's career interests. The study secured IRB approval at all three institutions.

Participant demographics are shown in Table 3.4. Because this sample occurred toward the end of the year-long teaming experience, the students had the greatest opportunity to interact with their teammates and faculty advisor, allowing for more informed survey responses.

Table 3.4: Sample demographics.

	2014 Data†											AY 2014-2015††			
Site	2014 ME Bachelor's Degree Awarded	Black	Asian	Hispanic	Native American	Pacific Islander	White	Race Not-reported	Inter-national	Male	Female	2014-2015 Enrollment	# Teams	Avg. Team Size	% Externally Sponsored Teams
Site A	320	1.3%	6.3%	4.7%	0.0%	0.0%	75.9%	0.0%	7.2%	91.9%	8.1%	342	43	9	56%
Site B	90	3.3%	4.4%	11.1%	2.2%	0.0%	73.3%	0.0%	2.2%	92.2%	7.8%	137	27	5	100%
Site C	88	1.1%	3.4%	4.5%	0.0%	0.0%	85.2%	0.0%	1.1%	86.4%	13.6%	150	29	5	41%
National	25042	2.4%	7.8%	8.5%	0.3%	0.2%	63.9%	0.0%	6.2%	87.2%	12.8%	N/A	N/A	N/A	N/A

†Data from Yoder (2014).
†† Data gathered from course coordinators.

Non-mechanical engineers were permitted to enroll in these courses. 88% of the total population consisted of Mechanical Engineering (ME) students; 7% was Electrical Engineering/Computer Engineering/Computer Science (EE/CS), 3% was General Engineering (GEN), and 2% was Other. The other category comprised students in chemical engineering, civil/environmental engineering, and industrial/systems engineering majors. At site A, 4.7% of the students self-identified as a member of the Corps of Cadets. 100% of the students were in the military training program at sites B and C.

3.4.2 Addressing Research Question 1: Internal Structure

To examine the leadership scales that emerge from the reduced set of 14 MLQ items, this study examined the end-of-course responses to the round-robin survey. Variables included the 14-item subset of the MLQ first established by Novoselich and Knight (2015) as shown in Table 3.5. To address research question one, we used confirmatory factor analysis to verify the ME Capstone (three-scale) leadership model that emerged from exploratory factor analysis in Novoselich and Knight (2015). Confirmatory factor analysis (CFA) is a theory-driven confirmatory technique and is one of the most commonly used multivariate techniques for testing measurement models that incorporate both observed and unobserved variables (Babakus, Ferguson, & Jöreskog, 1987). Theoretical relationships between the observed variables (i.e., individual survey items) and unobserved variables (i.e., leadership constructs) drive the analysis. To conduct the analysis, the researcher creates a hypothesized covariance matrix of the observed variables through the specification of a model. The analysis compares this hypothesized covariance matrix with the observed covariance matrix to determine how well the model fits the observed data (King, Nora, Stage, Schreiber, & Barlow, 2006). This technique allows for the verification of the three leadership constructs that were first identified by Novoselich and Knight (2015).

Table 3.5: Research Question 1 MLQ Items and Associated Scale Variables

Leadership Scale	**Leadership Factor**	**MLQ Item***
Transformational/ Contingent Reward (TCR)	Individualized Concern	31
	Intellectual Stimulation	32
	Inspirational Motivation	26
	Contingent Reward	35
	Idealized Influence (Behavior)	14
	Idealized Influence (Attributed)	10
Active Management by Exception (MEA)	Management by Exception (Active)	22
		27
		4
		24
Passive-Avoidant (PA)	Laissez-Faire	5
	Management by Exception (Passive)	12
		3
	Laissez-Faire	7

*Item text not included due to copyright agreement.

In addressing research question 1, 18 student responses (4.3%) had missing data that were excluded listwise, resulting in 428 total cases for analysis. To conduct CFA on the data, each dyadic leadership rating was considered a separate case. Because of the round-robin data collection methods employed for this study, the 428 student responses resulted in a total of 2,822 leadership dyads (i.e., rater to ratee combinations). The sample greatly exceeded the minimum 10 cases necessary for each estimated parameter for successful analysis recommended by King et al. (2006); Pedhazur and Schmelkin (1991) recommended a minimum of 200 cases overall. To further investigate potential violation of the case independence assumption of CFA because of the round-robin (360-degree) data collection methods used, an experiment using 1000 iterations of individual rater random samples was conducted and indicated that non-independence of the data did not affect results.

CFA results provide internal structure related validity evidence for the Full Range of Leadership model within the capstone design team context. Consistent with the recommendations of King et al. (2006) we used the Tucker-Lewis non-normed fit index (TLI), the comparative fit index (CFI), and the root mean square error of approximation (RMSEA) fit indices to assess model fit. In general, fit indices assess where the fit statistic T falls on a continuum from a total lack of fit (0) to a fully saturated fit (1) which would completely mimic the observed data (Bentler, 1990). TLI adjusts for the degrees of freedom for better fit near 1 (Bentler, 1990). CFI corrects for sample size and performs better for small samples (Hooper, Coughlan, & Mullen, 2008). RMSEA, in contrast, describes how well the model with optimally chosen parameter estimates fits the covariance matrix (Hooper et al., 2008). Following CFA, Cronbach's Alpha provided a measure of reliability of each scale, which indicates the internal consistency of each scale (Cortina, 1993; Gliem & Gliem, 2003).

3.4.3 Addressing Research Question 2: Relationships to Other Variables

To address research question 2 (i.e., determining relationships between the three leadership scales and other variables), only teams with a 100% response rate were considered. Because leadership scales that comprised the dependent variables were calculated as mean responses of all team members rating an individual team member, full team participation was necessary. Listwise exclusion of incomplete teams resulted in a total of 209 student cases, representing 45 complete teams (see Table 3.6). 10 of these teams were student-identified sub-teams of larger capstone design projects.

Although all team members in this sub-sample completed surveys, 22 students (10.5% of the sample, and only 0.47% of all possible survey item responses) submitted incomplete surveys that were imputed conforming with the recommendations of Cox, McIntosh, Reason, and Terenzini (2014). Of the missing items related to non-dyadic survey items (e.g., sex identification or international status) five missing responses were imputed. To treat the remaining 159 missing dyadic responses to leadership ratings (i.e., team member rating of another team member), traditional imputation was not applicable because the participant response referenced an external person rather than being generated internally (Huisman, 2009). Instead, missing dyadic ratings were replaced by the mean rating of the other team members regarding the rated individual, which is a common method of missing data treatment (Cox et al., 2014).

Table 3.6: Research Question 2 Full Team Response Subsample Demographics

	Sample Size	Black	Asian	Hispanic	Native American	Pacific Islander	White	Multi-Race	Inter-national	Male	Female
Sub-Sample	209	2.4%	6.7%	7.2%	0.0%	0.0%	78.9%	4.8%	3.3%	90.9%	9.1%

Dependent variables used to address research question two were the three leadership scale variables (TCR, MEA, and PA), which were calculated as the mean rating of all team members across all component items regarding the rated individual.

Independent variables were collected from students along with the round-robin type descriptive leadership statements.

The 6-item ***leadership skills*** scale used in the Prototype to Production (P2P) study of Engineer of 2020 outcomes (see Lattuca, Terenzini, Knight, & Ro, 2014) (Appendix B) measured students' self-reported *leadership skills*.

To measure student self-report perceptions of ***member effort***, we use an adaptation of the 5-item motivation scale employed by (Godard, 2001) in their study of the Canadian workforce. Appendix B provides a summary of the original version and modified items that were used in this study to quantify team *member effort*. For this study, the mean scores of the five adapted questions comprised a single scale variable with high internal consistency (α=0.92).

Measurement of a student's ***engineering GPA*** takes the form of student self-reported grades in their engineering specific course sequence. Previous studies have indicated that self-reported GPA provides a reasonable proxy for students' engineering discipline performance (e.g., Schlemer & Waldorf, 2010; Watson, 1998). A categorical item on the survey collected engineering course specific GPA from the students, as follows: 1.49 or below (Below C-), 1.50-1.99 (C- to C), 2.00-2.49 (C to B-), 2.50-2.99 (B- to B), 3.00-3.49 (B to A-), and 3.50-4.00 (A- to A).

To investigate relationships between the continuous variables of self-reported *leadership skills* and *member effort*, we used the Pearson Product Moment Correlation Coefficient (r) (Howell, 2013). These analyses determined magnitude, direction, and statistical significance of relationships between the variables.

For analysis of the student *engineering GPA* groupings, the small group sizes prevented a normal distribution of the student scale scores; thus, non-parametric tests were appropriate (Howell, 2013). To investigate group differences across GPA groupings, and in accordance with recommendations by Corder and Foreman (2014) and Howell (2013), we used the Kruskal-Wallis one-way analysis of variance test to first investigate whether any differences existed across student groups. The procedure tests the null hypothesis that all samples were drawn from identical populations (Howell, 2013). We then conducted post-hoc Mann-Whitney U tests to determine which pairs of student groups exhibited the differences. This analysis further determined the validity of the leadership scales through criterion related evidence as described by Gall, Gall, and Borg (2007) and Goodwin (2003).

3.4.4 Limitations

This study has several limitations which should be considered when interpreting results. First, this study focuses on senior-level engineering students mainly within the mechanical engineering discipline. As a result, generality claims to the wider field of engineering across multiple disciplines, class years, and professional practice are unwarranted. Second, the format of data collection, which only incorporates data collection from students but not the faculty advisors or external clients, truncates potential sources of leadership within the student teams. This decision was made in an effort to lessen data collection complexity. Requiring data collection from faculty advisors would have increased risk to the study's viability because of a greater potential for incomplete data with low faculty advisor participation. This facet of the study design, however, reflected the reality that students may not possess the expert or legitimate social power by which to influence their faculty advisors through leadership actions. The inclusion of external clients was also deemed beyond the scope of the study and could be an area for future work.

A third limitation of this study is the reduced number of MLQ items included in the survey. Although a full examination of all 36 MLQ leadership descriptive statements was desired, low student response rates in pilot data collection efforts prompted the decision to decrease the survey length. Examining all 36 MLQ items through exploratory factor analysis helped ensure the most advantageous subset of MLQ items were brought forward from pilot work into the current study. Results from this study do not imply validity of the full MLQ within the same context and should be an area of future research.

3.5 Results and Discussion

3.5.1 ME Capstone Leadership Model Verification

To verify the ME Capstone leadership model that emerged from the Novoselich and Knight (2015) analysis, we used the SEM library in R to conduct a confirmatory factor analysis. We chose the maximum likelihood estimation because of its robustness for the Likert-scale data analyzed with skewness and kurtosis generally less than 2 (see Table 3.7), as described by Muthén and Kaplan (2011). The covariance matrix shown in Table 3.8 was used to test model fit.

Table 3.7: Descriptive Leadership Statement Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
						Statistic	Error	Statistic	Error
MEP3	2822	1.0	5.0	1.954	1.2238	1.107	.046	.127	.092
MEA4	2822	1.0	5.0	2.530	1.3826	.388	.046	-1.104	.092
LF5	2822	1.0	5.0	1.569	.9913	1.877	.046	2.916	.092
LF7	2822	1.0	5.0	1.678	1.0432	1.542	.046	1.605	.092
IIA10	2822	1.0	5.0	3.584	1.3773	-.613	.046	-.865	.092
MEP12	2822	1.0	5.0	1.827	1.1135	1.299	.046	.841	.092
IIB14	2822	1.0	5.0	3.569	1.3085	-.579	.046	-.771	.092
MEA22	2822	1.0	5.0	2.970	1.4099	.018	.046	-1.251	.092
MEA24	2822	1.0	5.0	2.902	1.4191	.061	.046	-1.268	.092
IM26	2822	1.0	5.0	3.533	1.2631	-.507	.046	-.750	.092
MEA27	2822	1.0	5.0	2.895	1.4129	.029	.046	-1.258	.092
IC31	2822	1.0	5.0	3.429	1.3612	-.422	.046	-.998	.092
IS32	2822	1.0	5.0	3.521	1.2580	-.489	.046	-.742	.092
CR35	2822	1.0	5.0	3.941	1.1897	-.960	.046	-.006	.092

Table 3.8: Round 2 Data Covariance Matrix

	MEP3	MEA4	LF5	LF7	IIA10	MEP12	IIB14	MEA22	MEA24	IM26	MEA27	IC31	IS32	CR35
MEP3	1.50													
MEA4	0.09	1.91												
LF5	0.72	-0.01	0.98											
LF7	0.75	0.00	0.71	1.09										
IIA10	-0.50	0.35	-0.56	-0.57	1.90									
MEP12	0.94	0.08	0.78	0.77	-0.59	1.24								
IIB14	-0.55	0.30	-0.56	-0.57	1.07	-0.64	1.71							
MEA22	-0.29	0.81	-0.33	-0.34	0.67	-0.35	0.75	1.99						
MEA24	-0.26	0.77	-0.33	-0.33	0.65	-0.33	0.77	1.34	2.01					
IM26	-0.56	0.34	-0.59	-0.59	1.02	-0.65	1.23	0.78	0.88	1.60				
MEA27	-0.26	0.88	-0.31	-0.29	0.59	-0.31	0.84	1.15	1.26	0.93	2.00			
IC31	-0.63	0.33	-0.62	-0.62	1.06	-0.71	1.28	0.77	0.86	1.31	0.97	1.85		
IS32	-0.56	0.32	-0.58	-0.55	0.86	-0.67	1.10	0.73	0.79	1.14	0.88	1.30	1.58	
CR35	-0.50	0.20	-0.52	-0.50	0.86	-0.55	0.96	0.59	0.61	0.98	0.67	1.14	1.00	1.42

The model fit statistics shown in Table 3.9 indicate good fit between the model and the observed data in accordance with recommendations by King et al. (2006) and Pedhazur and Schmelkin (1991). These results show that the ME Capstone leadership model identified by Novoselich and Knight (2015) with exploratory factor analysis of 2013–2014 academic year data is a good fit for students completing their 2014–2015 capstone design experience.

Table 3.9: CFA Model Summary

	Results
Number of Cases	2822
RMSEA	0.06 (<0.06-0.08)
95% CI	0.06-0.06
Tucker-Lewis NNFI (TLI)	0.96 (>0.95)
CFI	0.97 (>0.95)

Note: King et al. (2006) good fit cutoff in parentheses.

The path diagram shown in Figure 3.3 illustrates that the 14 leadership descriptive statements (boxes) reduce into the three leadership scales (circles) described by Novoselich and Knight (2015). Figure 3.3 shows the standardized factor loadings (coefficients) for all paths identified (unidirectional arrows) and the unique variance associated with each observed variable (circular, bi-directional arrows). Unstandardized coefficients, error terms, z values, and associated probabilities are presented in Table 3.10[4]. The strong factor loadings and low p values (<0.001) indicate that the 14 observed descriptive leadership statements are predicted by the latent TCR, MEA, and PA leadership constructs. The latent construct accounts for over 70% of the variance in observations for 12 of the 14 leadership descriptive statements (exceptions are MEA4 and IIA10). For MEA 4, the MEA construct accounted for only 51% of the variance. This items asked about deviations from standards. The additional variability of this item may be attributed to students' interpretation of the word ‘standards’ differently--it may have been interpreted as published engineering specific standards (e.g., ASTM) or more generally as standards of conduct. For IIA10, the TCR construct accounted for only 66%

[4] Factor loadings in Figure 3.3 and Table 3.12 represent regression coefficients for the latent construct predicting the observed variable (Brown, 2006). The variance terms indicate the residual variance of the observed leadership descriptive statement not accounted for by the latent construct (Brown, 2006).

of the variance. This item asked about instilling pride in an individual and could be subject to multiple interpretations as well.

Correlation coefficients between the three leadership scales provide additional evidence of validity. The results are consistent with the positioning of the component factors of each construct along the activity and effectiveness continua shown in Figure 3.4 and described by Antonakis and House (2013); Bass (1985); Bass and Avolio (1994); Northouse (2013). There is a strong, positive correlation between the TCR and MEA scales (correlation = 0.64), which indicates that students who rated their teammates highly in TCR behaviors also tended to rate those same individuals highly in MEA behaviors. The strong, positive correlations between MEA and TCR provide preliminary indications that MEA behaviors may be more associated with active and effective leadership within the design teams because of TCR's consistent, strong relationships with positive outcomes discussed in the literature review. The PA scale had a strong, negative correlation with TCR (correlation = -0.63) and a negative, but weaker correlation to the MEA scale (correlation = -0.29). TCR and PA are on extreme ends of the two continua, which may account for widely differing views of an individual's leadership. This difference in perceptions of a person's leadership would explain the strong, negative correlation between TCR and PA. MEA is positioned between PA and TCR, showing less differences in behaviors. This location would account for the lower magnitude, negative correlation between PA and MEA. The consistency of these findings with theoretical explanation of the leadership model adds evidence to the validity of the model for the capstone design team context.

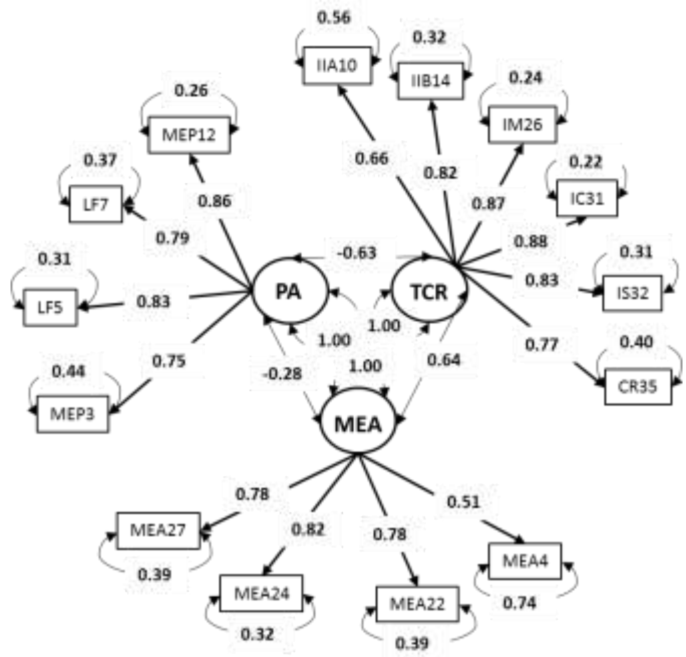

Figure 3.3. Path Diagram for the Model with Standardized Coefficients**.**

These results show internal structure evidence of validity in the capstone design team context. The three-scale model first established using exploratory factor analysis by Novoselich and Knight (2015) fits this more recent, expanded data set and measures constructs conceptually similar to those of previous adaptations of the Full Range of Leadership model. In addition to the evidence of validity for the three-scale leadership model gained through confirmatory factor analysis, the reliability of the three scales was also examined. For all three leadership scales, Cronbach's Alpha values greater than 0.70 (Table 3.11) indicated that the scale variables consistently measured their higher order leadership constructs (Cortina, 1993; Douglas & Purzer, 2015); thus, the scales were measured reliably across participants (American Educational Research Association et al., 2014). A second confirmatory factor analysis using course mid-point data showed that the model also held at the mid-point of the course (Appendix C) [5].

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[5] A second confirmatory factor analysis using data collected in the middle of the semester also demonstrated good fit and stability of the leadership constructs over the breadth of the capstone design experience. A full explanation of this analysis is included in Appendix C. The model also indicated good fit on 1000 iterations of individual rater random samples, which experimentally assessed a potential violation of the independence assumption caused by the round-robin (360-degree) data collection format for this study. A full explanation of that analysis is included in Appendix D.

Table 3.10: Unstandardized Parameter Estimates of Round 2 CFA model.

Parameter	Estimate	Std Error	z Value	Pr(>|z|)
TRANSFORMATIONAL/CONTINGENT REWARD->IIA10	0.91	0.02	42.45	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD->IIB14	1.08	0.02	57.87	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD->IM26	1.1	0.02	63.36	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD->IC31	1.2	0.02	64.60	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD->IS32	1.05	0.02	58.82	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD->CR35	0.92	0.02	52.60	0.00E+00
ACTIVE_MANAGEMENT_BY_EXCEPTION->MEA4	0.7	0.02	29.34	3.63E-189
ACTIVE_MANAGEMENT_BY_EXCEPTION->MEA22	1.1	0.02	50.63	0.00E+00
ACTIVE_MANAGEMENT_BY_EXCEPTION->MEA24	1.17	0.02	54.72	0.00E+00
ACTIVE_MANAGEMENT_BY_EXCEPTION->MEA27	1.11	0.02	50.95	0.00E+00
PASSIVE_AVOIDANT->MEP3	0.92	0.02	49.40	0.00E+00
PASSIVE_AVOIDANT->LF5	0.82	0.01	57.18	0.00E+00
PASSIVE_AVOIDANT->LF7	0.83	0.02	53.33	0.00E+00
PASSIVE_AVOIDANT->MEP12	0.96	0.02	60.39	0.00E+00
MEP3<->MEP3	0.65	0.02	34.84	6.21E-266
MEA4<->MEA4	1.42	0.04	38.88	0.00E+00
LF5<->LF5	0.30	0.01	30.07	1.16E-198
LF7<->LF7	0.40	0.01	32.84	1.53E-236
IIA10<->IIA10	1.07	0.03	38.97	0.00E+00
MEP12<->MEP12	0.32	0.01	26.93	9.14E-160
IIB14<->IIB14	0.55	0.02	35.10	6.27E-270
MEA22<->MEA22	0.78	0.03	30.37	1.32E-202
MEA24<->MEA24	0.65	0.02	26.39	1.96E-153
IM26<->IM26	0.38	0.01	31.97	2.75E-224
MEA27<->MEA27	0.77	0.03	30.10	4.46E-199
IC31<->IC31	0.41	0.01	30.98	1.01E-210
IS32<->IS32	0.48	0.01	34.68	1.70E-263
CR35<->CR35	0.57	0.02	36.93	1.37E-298
TRANSFORMATIONAL/CONTINGENT REWARD<->ACTIVE_MANAGEMENT_BY_E	0.64	0.01	51.53	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD<->PASSIVE_AVOIDANT	-0.63	0.01	-52.09	0.00E+00
ACTIVE_MANAGEMENT_BY_EXCEPTION<->PASSIVE_AVOIDANT	-0.29	0.02	-16.11	2.24E-58

Table 3.11: Leadership Scale Reliability (Cronbach's Alpha)

Leadership Factor/Scale	Alpha
Transformational/ Contingent Reward (TCR)	0.92
Active Management by Exception (MEA)	0.82
Passive-Avoidant (PA)	0.88

3.5.2 Interpretation of the three leadership scales

The CFA results indicate that the ME capstone version of the Full Range of Leadership model, as measured by the 14-item subset of the MLQ, is practiced by the mechanical engineering-centric capstone design team members in three ways: 1) Transformational/Contingent Reward, 2) Active Management by Exception, and 3) Passive-Avoidant (Figure 3.4). These three constructs are conceptually similar to but distinct from the Transformational, Transactional, and Laissez-Faire constructs of the Full Range of Leadership model, which are depicted in gray in Figure 3.4.

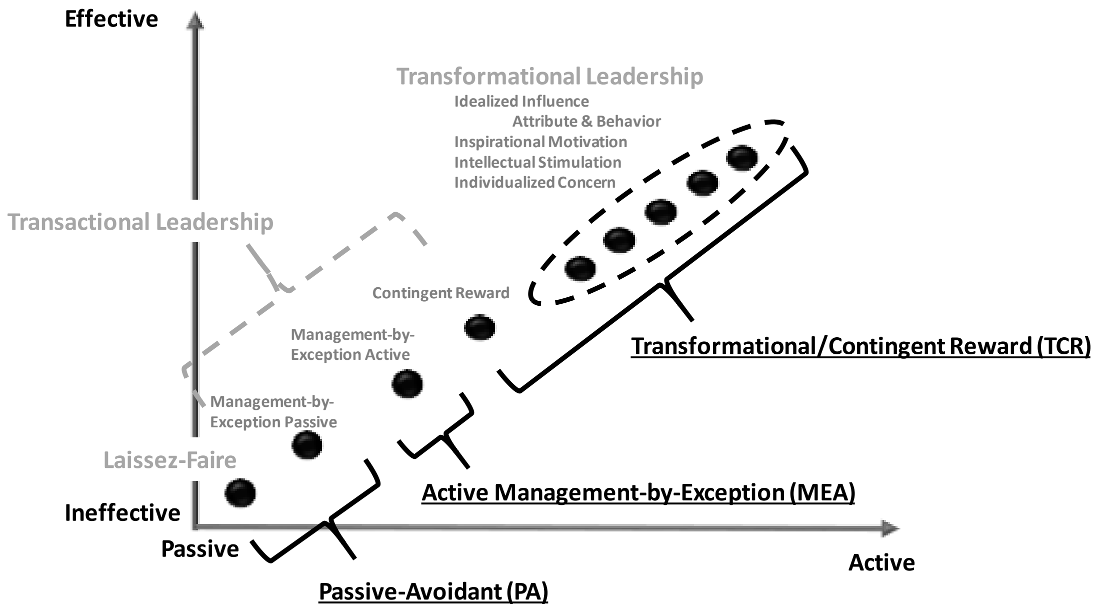


Figure 3.4. ME Capstone and Original Full Range of Leadership adapted from (Northouse, 2013, p. 192)

The Transformational/Contingent Reward construct characterizes leaders as developing team member strengths, maintaining a compelling vision, showing strong sense of purpose, and instilling pride in team members. This construct pulls mainly from transformational leadership behaviors but also incorporates contingent reward behaviors. Considering that contingent reward behaviors are often considered the quintessential components of transactional leadership (Bass, 1985; Hinkin & Schriesheim, 2008; Northouse, 2013), this finding may appear problematic. These loadings may stem from a blurring of the boundaries between individualized consideration and contingent reward factors that Bass (1997) acknowledges. Both individualized consideration and contingent reward focus on developing individuals, but Bass (1997, p. 134) states, “Individualized consideration focuses more attention on personal growth and recognition, whereas contingent reward attends more to promising or providing material rewards or resources.” Thus, the combination of contingent reward with transformational behaviors may have been observed because of the nature of the incentives engineering students may have to offer one another. Practicing engineers and corporate leaders may offer bonuses, time off, additional resources, or promotions; in contrast, students may be more apt to offer incentives that are transformational in nature, such as positive reinforcement for their efforts or additional assistance with project tasks.

The Active Management by Exception construct characterizes leaders as those who maintain a consistent focus on standards, as well as those who identify and track mistakes among team members. As indicated by the name, this construct incorporates the "management" aspect of leadership to ensure team members are “doing things right” (Rost, 1993, p. 220) and is typified by negative reinforcement by a leader when something goes wrong. These types of behaviors can induce effort from a teammate to comply with team standards, preventing negative consequences for failure (Bass, 1985). In their re-examination of the MLQ, Avolio et al. (1999) described a leader who practices active management by exception as someone who “focuses on monitoring task execution for any problems that might arise and correcting those problems to maintain current performance levels” (p. 445). Management by exception may be particularly important in an engineering design context where a lack of adherence to engineering principles and design standards can have catastrophic effects. The isolation of this construct separately from TCR and PA behaviors may stem from common challenges in maintaining standards for team-based engineering projects. Deficiencies in work load balance (Borrego, Karlin, McNair, & Beddoes, 2013; Paretti, Pembridge, Brozina, Lutz, & Phanthanousy, 2013) and student capability (Paretti et al., 2013) are recurring challenges for student team-based engineering projects. The negative reinforcement characterized by this leadership construct may be necessary for students to overcome these pervasive challenges during their teaming experiences to meet standards of performance and engineering design rigor required for successful prototype functioning.

The Passive-Avoidant construct characterizes leaders by either a delay in action until serious issues arise or a total absence of involvement, especially when needed. This construct combines the laissez-faire and passive management by exception factors of the Full Range of Leadership model. These leadership behaviors are consistently ineffective but may be necessary in some situations, like when managing large teams (Antonakis & House, 2013), as the leader may not have the capacity to attend to all facets of the team. There are several potential reasons for students to exhibit these types of leadership behaviors. First, as novice engineers and engineering leaders, inattentive behaviors may be a function of inexperience. Students may only realize a problem exists once it has become serious. Second, for students in capstone design, these leadership behaviors may be a result of de-prioritizing the capstone design project as it is typically only one course among multiple taken in their senior year. As students prioritize multiple competing requirements, their capstone design projects may not receive their full attentions. Third, students may not be labeled as having a position of leadership within the team and consequently may provide minimal influence among their teammates.

3.5.3 Evidence of Validity for Leadership Scales

Addressing research question 2, the partial or full support of all hypotheses (Table 12) indicate that the leadership scales demonstrate evidence of validity. Overall, results indicated that students differed in their scores across the TCR and PA scales with regards to self-reported *leadership skills*, *member effort*, and *engineering GPA* and *leadership skills* had stronger relationships than *member effort*. The MEA scale showed limited group differences in *engineering GPA* only.

Table 3.12: Summary of Hypotheses.

Hypothesis	**Results**
Hypothesis 1: A self-report measure of leadership skills positively correlates with both the peer-rated TCR and MEA leadership scales and negatively correlates with the peer-rated PA scale.	Partial Support (TCR, PA)
Hypothesis 2: TCR and MEA Leadership scales positively correlate with a self-report scale of member effort, and PA negatively correlates with a self-report scale of member effort.	Partial Support (TCR, PA)
Hypothesis 3: Correlation coefficients between self-reported member effort and the TCR, MEA, and PA leadership scales will have a lower magnitude than correlation coefficients between the self-reported leadership scale and the TCR, MEA, and PA scales.	Partial Support (TCR, PA)
Hypothesis 4: Students with higher self-reported engineering course GPA have higher peer-ratings on both TCR and MEA leadership scales and lower ratings on the PA leadership scale.	Supported

3.5.3.1 Correlation analysis results (Hypotheses 1-3)

Students' levels of self-reported *leadership skills* and *member effort* exhibited significant relationships with their team ratings for each of the three leadership scales (Table 3.13), as indicated by Pearson Product Moment Correlation Coefficient (r).

Following the recommendations of Osborne and Overbay (2004) and Judd and McClelland (1989), bi-variate outliers with residuals greater than three standard deviations were deleted pairwise, which accounts for the varying n values across analyses in Table 3.13. These results provided support to both hypotheses 1 and 2.

Table 3.13: Correlation Analysis Results Summary.

	Transformational/ Contingent Reward			**Active Management by Exception**			**Passive-Avoidant**		
	r	**p**	**n†**	**r**	**p**	**n†**	**r**	**p**	**n†**
Leadership Skills	0.30	<0.001	208	0.08	0.13	206	-0.27	<0.001	206
Member Effort	0.21	0.001	208	-0.02	0.39	207	-0.23	0.001	206

Hypothesis 1 was partially supported. Self-reported *leadership skills* exhibited the anticipated relationships with both the TCR and PA scale variables but not with the MEA scale. Levels of student self-reported *leadership skills* had a moderate, statistically significant, positive relationship with their teammates' mean ratings on the TCR scale (i.e., students who thought they were more capable leaders were rated higher by their teammates on the TCR items). The MEA scale, however, exhibited no significant relationship—students' self-reported *leadership skills* did not correlate with their teammates' ratings of their MEA behaviors. As expected, there was a negative relationship between students' *leadership skills* and their PA ratings.

The lack of significant relationship between *leadership skills* and the MEA scale may be attributed to the *leadership skills* scale measuring actions that are more transformational in nature, relating more heavily to TCR behaviors than to the accountability actions measured with the MEA scale. Within *leadership skills*, five of the six items—harnessing member strengths, identifying paths to progress, developing plans, taking responsibility, and motivating others—are consistent with the actions of transformational leadership (see Appendix B). The remaining item, regarding monitoring the design process to ensure goal accomplishment, is conceptually more similar to MEA than TCR. Therefore, the unbalanced similarity between the *Leadership skills* scale and TCR relative to MEA might explain the stronger observed relationship

Hypothesis 2 was partially supported. Member effort also exhibited the anticipated relationships with the TCR and PA scale variables but not with the MEA scale. Self-reported *member effort* had a weak, statistically significant, positive relationship with their teammates' mean ratings of them on the TCR scale (i.e., students who thought they were putting forth more effort on the project were rated higher by their teammates on the TCR items). As expected, there was also a negative relationship between students' self-reported *member effort* and their PA ratings.

The MEA scale did not exhibit a significant relationship with the *member effort* scale; perhaps the varying degrees of effort required to actively manage the work of team members plays a role in this lack of relationships. One potential explanation for this finding may be that the negative reinforcement and criticisms associated with MEA may take varying degrees of effort for engineers to enact. For blatant displays of failures to achieve standards, such as absence or inattentiveness at team meetings and working session, observation and criticism requires relatively low effort. Conversely, for complex design problems, requiring precise application and interpretation of engineering principles, observing and correcting these types of errors may require thorough, rigorous examination, a marked increase in associated leader effort. Because the effort required to maintain accountability of team member actions may vary widely, this increased variance may explain the lack of correlation between the MEA scale and *member effort*. The lack of significant relationship between effort and MEA is an area of further study to determine how and why students actively manage other team members.

Hypothesis 3 was fully supported. Across all three leadership scale variables, correlation coefficients for *member effort* were lower than for *leadership skills*. The TCR scale had an r=0.30 correlation with *leadership skills* but only an r=0.21 correlation with *member effort*. The MEA scale had an r=0.08 correlation with *leadership skills* but only an r=-0.02 correlation with *member effort.* The PA scale had an r=-0.27 correlation with *leadership skills* but only an r=-0.23 correlation with *member effort.* Multiple regression analyses corroborated the stronger relationship between *leadership skills* and the leadership scale variables (Table 3.14). When *leadership skills* and *member effort* were considered together in multiple regression models, the relationship between *leadership skills* and both TCR and PA scales remained significant, but member effort was not.

Standardized regression coefficients (β) were also larger for *leadership skills* than *member effort*. In total, these results indicated that the TCR and PA scales were in fact more related to leadership than effort, partially supporting hypothesis 3.

Table 3.14: Multiple Regression Analysis Results Summary.

	Transformational/ Contingent Reward			**Active Management by Exception**			**Passive-Avoidant**		
	B	**β**	**p**	**B**	**β**	**p**	**B**	**β**	**p**
Leadership Skills	0.21	0.215	0.005	0.08	0.10	0.221	-0.15	-0.181	0.018
Member Effort	0.09	0.089	0.239	-0.04	-0.05	0.535	-0.08	-0.091	0.232
Constant	2.554		<0.001	2.673		<0.001	2.565		<0.001

3.5.3.2 Student Engineering GPA Differences (Hypothesis 4)

Hypothesis 4 was supported. Student group differences occurred across the breadth of engineering GPA bands (note: students who reported grades below B- were consolidated into a single group in these analyses). Consistent with the previously reviewed literature, Figure 3.5 and Table 3.14 show positive relationships between the TCR scores and students' engineering GPA. MEA scores also exhibited a positive, albeit limited relationship. PA mean scores, contrastingly, exhibited a negative relationship with engineering GPA.

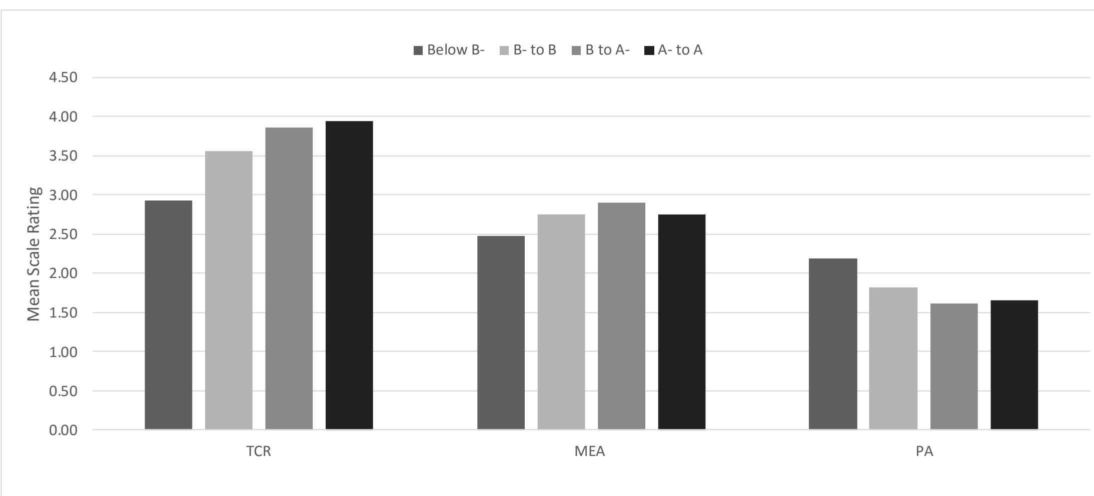


Figure 3.5. Leadership Scale Variable Mean Comparison[6].

[6] Although the Mann-Whitney U test compares the mean ranks of cases rather than group means themselves (Howell, 2013), the bar plots of group means are shown in Figure 3.5 for clarity, as they are more readily interpretable than mean rankings.

Post-hoc Mann-Whitney U test analyses displayed in Table 3.15 confirmed that leadership scale scores for students in the B to A- group differed significantly from the below B- student group at the α=0.05 level or below on all three leadership scales. All other student groupings generally differed for both the TCR and PA scales. The results provide additional evidence of validity through a relationship to other variables (Goodwin, 2003) in that student groups that should theoretically differentiate themselves with regard to leadership are in fact showing significant differences across all three of the leadership scales.

Table 3.15: Engineering GPA Group Mann-Whitney U test results.

	Below 2.50 Below (B-)	**2.50-2.99 (B- to B)**	**3.00-3.49 (B to A-)**	**3.50-4.00 (A- to A)**
Transformational/Contingent Reward				
Below 2.50 (B-) (13)				
2.50-2.99(B- to B) (50)	+**			
3.00-3.49 (B to A-) (88)	+**	+**		
3.50-4.00 (A- to A) (58)	+**	+**	N/S	
Active Management by Exception				
Below 2.50 (B-) (13)				
2.50-2.99(B- to B) (50)	N/S			
3.00-3.49 (B to A-) (88)	+*	N/S		
3.50-4.00 (A- to A) (58)	N/S	N/S	N/S	
Passive-Avoidant				
Below 2.50 (B-) (13)				
2.50-2.99(B- to B) (50)	N/S			
3.00-3.49 (B to A-) (88)	-**	N/S		
3.50-4.00 (A- to A) (58)	-**	-**	N/S	

Note 1: +=Positive Difference. -=Negative Difference; *$p \leq 0.05$, **$p \leq 0.01$
Note 2: N/S= Nothing Significant

3.6 Conclusions

For practitioners of engineering and engineering education, this study explores a model of leadership that can be used to coach and guide engineering students in their leadership practices and development. The three leadership constructs describe leadership behaviors in a way that can allow students to interpret and describe their leadership experiences within their capstone design teams in new ways.

As demonstrated by the follow-on inferential statistical analyses, the three leadership scales related to student self-report measures of leadership, effort, and engineering GPA differentially. These differences corroborate the fact that these scales are each measuring different facets of the leadership phenomenon. Although the factors that comprise the full range of leadership model were not fully measured in this study, the three higher order leadership scales that were confirmed in this study demonstrated evidence of validity in ways consistent with interpretations of the Full Range of Leadership model. As a result, this study indicates that the wide body of literature surrounding the Full Range of Leadership model may provide insights for engineers looking to apply or teach effective leadership concepts for engineering practice.

The TCR, MEA, and PA leadership constructs investigated in this study can provide a method for engineering students to better understand relevant facets of leadership within the design team context. Illuminating these three separate forms of leadership behaviors for engineering students and young engineers may make the often nebulous idea of leadership more concrete and nuanced towards their personal experiences in the capstone design space. Being able to relate these constructs to their engineering experiences, students may gain a basic level of leadership knowledge that can then be applied and reflected upon increasingly throughout their careers, as the National Academy of Engineering (2004) aspires.

3.7 Future Work

Although this research provides indications of what forms of leadership exist in engineering student design teams, the effectiveness of the different forms of leadership was beyond the scope of this study. Further investigation is warranted to determine how these forms of leadership and combinations thereof may contribute to enhanced learning for the engineering students and overall design team effectiveness. Although the Bass (1985) and Northouse (2013) descriptions of the Full Range of Leadership model may support transformational/contingent reward building upon active management by exception to produce team performance beyond expectations, empirical evidence is not currently available to support these assertions within the engineering design team context. Further study that relates leader behaviors across the three leadership forms to measures of student learning and team success would provide empirical support for more and less effective models of team leadership and is an area on on-going research for the authors. Further investigation could also examine the longitudinal development of each leadership form during a team's life cycle to determine if an optimal progression of development exists.

This specific research informs a larger study of shared leadership within the capstone design teams. The round-robin data collection technique used in this study allows for a network analysis of the student leadership ratings, which can be used to quantify the degree to which leadership across the three leadership scales is shared among the students and faculty advisor within each team as explained by (Mayo et al., 2003). Assessing shared leadership within the teams will further contextualize leadership practice in an engineering design setting to better align leadership practice to the collaborative environment experienced by engineers. An examination of how and to what degree teams combine and share leadership across the three constructs may allow for the classification and description of teams based on the forms of leadership that they enact. These classifications and descriptions may provide faculty and engineering professionals an additional set of tools with which to describe and understand teamwork, team leadership, and leadership practices related to student design team success.

The general lack of relationships between the MEA leadership scale and other variables indicates that students' MEA behaviors may be related to other variables not incorporated into this study. Qualitative study of student teams exploring how and why students, faculty, and external clients hold team members accountable for work within capstone design projects may provide greater insight on how MEA behaviors are operationalized within the capstone design team experience.

This research is also focused exclusively on the mechanical engineering capstone design context. Although this study provides critical insights into how students enact leadership in a key developmental experience prior to professional engineering practice, the study's focus on the mechanical engineering capstone design context prevents generalization across engineering disciplines and breadth of the undergraduate engineering experience. Further study is warranted within other engineering disciplines and across developmental stages from the first year to professional practice to address the applicability of this leadership model to the larger practice of engineering.

Chapter 4:

Manuscript 2: Shared Leadership in Engineering Teams: A social network analysis of mechanical engineering capstone design teams.

4.1 Abstract

Background

Multiple national-level reports have indicated the need for engineers to take more prominent leadership roles to better-inform complex policy decisions. Engineering faculty are tasked to develop a basic level of leadership knowledge within undergraduate engineering students that can then be applied increasingly throughout their careers. Recent engineering leadership literature, however suggests that an adequate model of how engineers lead does not exist and that engineers find the traditional, vertical conceptualizations incompatible with the collaborative nature of engineering practice. Several studies indicate that a shared leadership model may be more appropriate than the historically vertical leadership conceptualization for knowledge work similar to that found in student design teams.

Purpose/Hypothesis

This study examines the extent to which the Full Range of Leadership is shared within undergraduate, senior-level engineering capstone design teams and classify teams based on their level of leadership sharedness.

Design/Methods

This quantitative study examines round-robin (360-degree) student leadership ratings gathered from mechanical engineering capstone design team students using a 14-item subset of the Multifactor Leadership Questionnaire. Shared leadership is measured using social network analysis and operationalized as a combination of network decentralization and density across the three forms of leadership related to the Full Range of Leadership model. Cluster analyses of decentralization and density measures groups the design teams into a shared leadership classification system.

Results

Results suggest that leadership, on average, is more shared than centralized within capstone design teams. The amount of leadership varies across the three forms examined, in alignment with previous studies of the Full Range of Leadership model for student teams in other contexts. Classification results show that measures of shared leadership create dichotomous groupings of teams, facilitating a quadrant classification of shared leadership.

Conclusions

This study corroborates previous engineering teamwork research that encourages the conceptualization of leadership as shared within engineering student design teams. To allow students and practicing engineers to relate their design work experiences to concepts of leadership, shared leadership models may be more consistent than historical, vertical models. The results develop a taxonomy of how engineers lead within their design teams accounting for forms of leadership and levels of leadership sharing.

Key Words

Shared Leadership, Engineering Leadership, Mechanical Engineering Design, Full Range of Leadership model, Social Network Analysis

4.2 Introduction

For more than a decade, reports from industry and the federal government have called for the preparation of engineering students for leadership roles (e.g., ASME Center for Education, 2011; National Academy of Engineering, 2004, 2005), but this call has been largely unanswered (ASME Center for Education, 2011). For example, in comprehensive reviews of current engineering leadership education programs, Graham, Crawley, and Mendelsohn (2009) find these programs lacking a systematic approach to targeting 'leadership' as a specific outcome in engineering education. Outside the classroom, in 2014, only six of the 541 members of the U.S. Congress have had former employment as an engineer (Manning, 2014), and only 11 members hold some form of an engineering degree (Glanville, 2013). One potential barrier toward preparing engineering students as leaders may be vertical views of leadership that have dominated the literature historically (Jackson & Parry, 2011; Markham, 2012; Pearce & Conger, 2003b) and remain present in engineering practice (Rottmann et al., 2014). Rottmann et al. (2014) indicate that those traditional, top-down leadership perceptions lead to an aversion of leadership for some engineers and are inconsistent with the collaborative, team-based norms of engineering practice.

A gap in engineering related leadership literature may partially explain engineers' aversion to leadership. Recent literature suggests that an adequate model for how engineers lead in a team-based engineering context does not exist (e.g., Paul & Cowe Falls, 2015; Reeve et al., 2015; Rottmann et al., 2014). Engineering educators and practicing engineers currently cannot reference a leadership model that has been rigorously examined in an engineering team-based context, which may make leadership concepts unapproachable for engineers. Knight and Novoselich (2014) described a disconnect in leadership emphasis between the engineering classroom and industry practice, and Rottmann et al. (2014) found that some practicing engineers are uncomfortable with leadership concepts. Paretti et al. (2013) also describe how faculty may feel ill-equipped to intervene in teaming dynamics issues such as team conflict and workload imbalances, of which leadership scholars assert leadership can play an integral part in preventing or alleviating (e.g., Hill, 2013). Leadership models that better relate leadership to the collaborative, team-based norms of engineering practice may help bridge these engineering-leadership disconnects.

This study investigates leadership from the perspective of such collaborative, team-based environments that engineers routinely experience. Leadership scholars indicate that *shared leadership*, characterized by the serial emergence of official as well as unofficial leaders, may be a more effective model than a vertical, individualistic approach (Feister et al., 2014; Pearce, 2004; Pearce & Conger, 2003b), especially for the creative, complex, and interdependent knowledge work like that of an engineering student design team setting. For such settings, which provide engineering students formative leadership experiences prior to professional practice, studies by Zafft et al. (2009) and Feister et al. (2014) indicate that leadership may be more shared than vertical among student team members, and both studies advocate for further exploration of shared leadership within student design teams.

The purpose of this study is to examine the degree to which leadership is shared within design teams. By empirically developing a shared leadership model within the engineering student design team context, this research may provide engineering faculty a conceptualization of leadership that better coincides with the collaborative norms of engineering practice. Specifically, the study addresses the following research questions:

RQ1. To what degree is leadership shared within undergraduate mechanical engineering-centric capstone design teams?

RQ2. To what degree does the level of shared leadership classify undergraduate mechanical engineering-centric capstone design teams?

4.3 Review of the Literature

4.3.1 Leadership Model

The Full Range of Leadership model informs this study's investigation of shared leadership. Previous literature has articulated the applicability of the Full Range of Leadership model for engineering contexts (e.g., Breaux, 2006; Novoselich & Knight, 2015), and links between the theory and leadership orientations within engineering professional practice have been proposed (e.g., Rottmann et al., 2014). Avolio et al. (2003) made an early attempt to assess shared leadership in a variety of non-engineering teams using the Full Range of Leadership model. Following the proposed research design of Mayo et al. (2003), more current work by Novoselich and Knight (Chapter 3) established the validity of an adapted version of the Full Range of Leadership model for shared leadership analysis within the mechanical engineering capstone design team context, which is incorporated into this study. This leadership model has been in existence for over two decades (see Bass & Avolio, 1994) and is operationalized with the well-established Multifactor Leadership Questionnaire (MLQ) (Bass & Avolio, 2013).

The Full Range of Leadership model aggregates a series of nine types of leader actions into three forms of leadership to explain how leaders can help their organizations or teams perform beyond expectations (Antonakis et al., 2003; Northouse, 2013; Wang et al., 2011). It describes how organizations can exceed expectations by augmenting a base of transactional leadership behaviors with transformational behaviors (Bass, 1985). Transactional leadership refers to the exchange of valued outcomes between leaders and followers, and transformational leadership is the set of behaviors that unite followers and changes their goals and beliefs (Kuhnert & Lewis, 1987). A third form of leadership, laissez-faire, describes absentee leadership behaviors and most often contributes to low organizational performance (Antonakis & House, 2013). Leaders enact all three forms of leadership to varying degrees.

Within the capstone design team context, recent work indicates that similar leadership scales occur in capstone design teams, consistent with other team-level examination of the Full Range of Leadership model. Using factor analysis in an inaugural examination of the model for capstone design teams, Novoselich and Knight (2015, Chapter 3) identified conceptually similar combinations of the nine leadership types, which grouped into three scales—transformational/contingent reward (TCR), active management by exception (MEA) and passive-avoidant (PA). Avolio et al. (2003) concluded that similar constructs, consisting of transformational/transactional, active management by exception, and passive/avoidant leadership may constitute a parsimonious model of leadership at the team level in their examination of the team version of the MLQ. Similar scales have also been identified and explored in previous examinations of the Full Range of Leadership model (e.g., Avolio et al., 1999; Boies, Lvina, & Martens, 2010). Novoselich and Knight (Chapter 3) describe TCR leadership as developing team member strengths, maintaining a compelling vision, showing strong sense of purpose, and instilling pride in team members for being associated with her or him. MEA leadership primarily involves negative reinforcement, having a consistent focus on maintaining standards in addition to identifying and tracking mistakes among team members (Antonakis & House, 2013; Avolio, 2011). Passive-avoidant leadership either delays action until serious issues arise or demonstrates a total absence of involvement, especially when needed (Avolio et al., 1999; Novoselich and Knight, Chapter 3). The original and ME capstone versions of the model are shown in Figure 4.1.

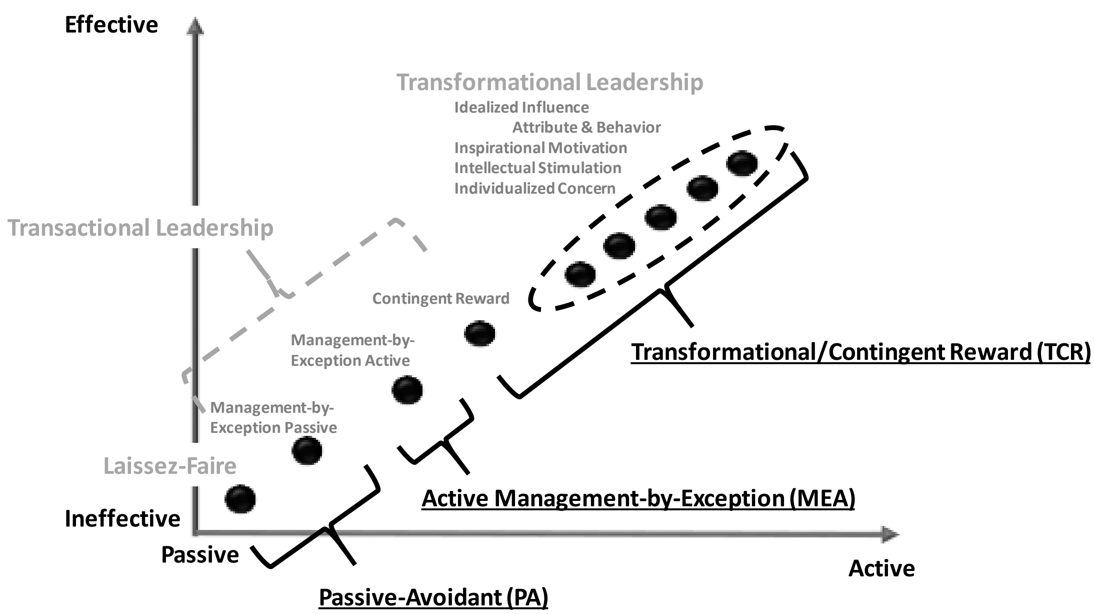


Figure 4.1. ME Capstone and Original Full Range of Leadership adapted from (Northouse, 2013, p. 192)

The Full Range of leadership model has demonstrated applicability for shared leadership research in addition to its vertical leadership roots. First developed by Burns (1978) and expanded by Bass (1985) as a vertical leadership model, more recent work has examined the model in a shared context. Avolio et al. (1996; 2003) examined the Full Range of Leadership performed collectively by teams, using the team as the referent, rather than an individual leader (Avolio, 2011). Although conducted in contexts other than engineering student design teams, these results provide preliminary evidence that the Full Range of Leadership model is applicable across a wide spectrum from a wholly individual phenomenon related to one leader to a collective phenomenon associated with an entire group. These studies demonstrate the potential for the Full Range of Leadership model to be applicable to a shared leadership context.

4.3.2 Shared Leadership

The shared leadership paradigm has emerged as a new conceptualization of leadership that promotes the active influence of multiple individuals toward goal accomplishment (Hoch, 2014; Mathieu, D'Innocenzo, Kukenberger, & Reilly, 2015; Pearce & Conger, 2003b). Whereas many leadership theories look at the traits or behaviors of leaders themselves (Derue, Nahrgang, Wellman, & Humphrey, 2011), the shared leadership paradigm focuses on how many individuals enact leadership within an organization or team (Hoch, 2014; Mathieu, D'Innocenzo, et al., 2015). Pearce (2004) has described shared leadership as, "a simultaneous, ongoing, mutual influence process within a team that is characterized by 'serial emergence' of official as well as unofficial leaders" (p. 48) within an organization. In this paradigm, leaders emerge from the group based on their knowledge, skills, or abilities to lead the team through tasks or challenges and then pass the mantle of leadership to others as the team's situation evolves. At its core, the concept revolves around previous conceptualizations of followers and their empowerment (Pearce & Conger, 2003b). For example, situational leadership theory prescribes that at the follower's final stage of development, the leader should adopt a delegating approach which involves low supportive and low directive behavior, enabling the follower to perform semi-autonomously in the accomplishment of their tasks (Blanchard, Oncken, & Burrows, 2000). The shared leadership paradigm furthers the boundaries of these semi-autonomous actions to include active influence of the organization toward goal accomplishment. Fletcher and Kaufer (2003, p. 24) describe the modern requirement for vertical leaders to differentiate themselves from the group while simultaneously interacting as an integral part of the group as a "paradox of shared leadership"(p. 24).

Shared leadership models may align leadership perceptions with current conceptualizations of knowledge and collaboration in design teams. The shared leadership paradigm's development accounts for the situated nature of knowledge; in this modern age of increased technology and rapid industrial pace, it is nearly impossible for one person to have the necessary knowledge, skills, and abilities for all aspects of highly intellectual work (Pearce, 2004) or necessary to make well informed leadership decisions independently. This setting aligns with Newstetter's (1998) description of student learning environments in engineering design teams, as well as Salas et al.'s (2007) integrative model of team effectiveness, which references team leaders (plural) not team leader (singular) and describes how shared cognition affects leadership and vice-versa. In light of this evolving knowledge distribution and new landscape of modern collaboration, Wageman and Gardner (2012) called for a re-examination of team leadership. These calls were echoed by Dorst (2008), who articulated the need to examine the context in which design is practiced. Outside of engineering, Cox, Pearce, and Perry (2003) similarly proposed a model of shared leadership to benefit new product development team performance. Therefore, empirical evidence to support the existence shared leadership in design teams may align the leadership phenomenon with other distributed practices of their work together, making leadership more approachable to design team members.

Studies indicate that shared leadership models may be better suited to the undergraduate engineering student design team context than a vertical model; evidence from other contexts corroborate the utility of a shared leadership model. A quantitative study by Zafft et al. (2009) and qualitative work by Feister et al. (2014) provide indications that students share leadership within their design team experiences. Using the Competing Values Framework, Zafft et al. (2009) found that student design teams exhibit a dispersion of different leadership profiles across the team and that increased dispersion related positively to team performance in terms of course grades. This quantitative study is corroborated by a qualitative study of engineering student team members, as Feister et al. (2014) found that students describe leadership as emergent and fluid within their teams despite having an appointed individual leader. In light of this literature, we propose the following:

Hypothesis 1: Leadership is more shared than vertical for engineering student design teams.

4.3.3 Classifying Leadership Sharedness in Teams

Operationalizing the Full Range of Leadership across a vertical to shared continuum may pose challenges to the accessibility of leadership concepts for engineering educators. Accounting for the Full Range of Leadership alone involves three distinct forms of leadership behaviors (Avolio et al., 1999; Bass & Avolio, 2013), and accounting for the sharing of each form adds yet another level of complexity. Developing a multi-layered model of shared leadership may require a method of simplification and visualization to make the concepts more approachable (Contractor, DeChurch, Carson, Carter, & Keegan, 2012).

Previous theoretical shared leadership literature provides a potential solution for team leadership classification. Mayo et al. (2003) propose a leadership quadrant system to differentiate teams based on their degree of shared or vertical leadership. In this quadrant system, Mayo et al. (2003) account for both the distribution and amount of leadership enacted by team members to classify teams into one of four categories: 1) Shared Leadership, 2) Low Shared Leadership, 3) Vertical Leadership, or 4) Leadership Avoidance (Figure 4.2).

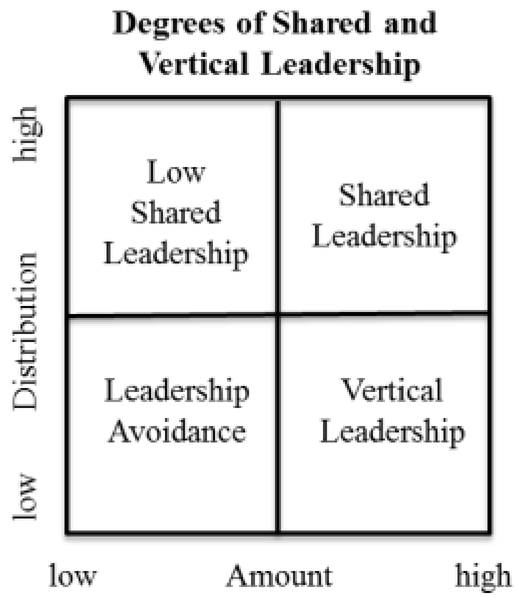


Figure 4.2. Team Shared Leadership Classifications.
(adapted from (Mayo et al., 2003)

This classification system remained conceptual and was not assessed with actual team data. Kukenberger (2012) operationalized a variation of this quadrant system to classify shared leadership for both undergraduate and graduate student business strategy teams and aviation manufacturing work teams and recommends use of a quadrant system to classify teams. In both contexts, the quadrants were adequate for partitioning teams into statistically different groups based on their levels of shared leadership. Similarly, using this quadrant system proposed by Mayo et al. (2003) for the TCR, MEA, and PA leadership forms, engineering educators may be able to classify teams into one of four quadrants in each of the three forms of leadership to fully account for leadership processes within design teams. In light of this potential strategy, an objective of this study is to determine if a quadrant classification system across the three forms of leadership accounted for in the Full Range of Leadership model adequately classifies levels of shared leadership for mechanical engineering-centric capstone design teams.

4.4 Data and Methods

4.4.1 Data Collection

Student surveys administered at the end of the spring semester of the 2014-2015 academic year comprise this study's data. Participants were enrolled in year-long (2014–

2015), team-based, mechanical engineering-centric, senior level capstone design courses at three institutions: a large, mid-Atlantic research university (site A) and two smaller engineering-focused military institutions (sites B and C). These study sites were purposefully chosen because of their historic leadership focus, ABET accredited engineering programs, comparable capstone design experiences, and access to participants. Qualitative comparison of course syllabi and team charter requirements across the three institutions indicated similarity in the capstone design experience with regard to course objectives, course content, project requirements, and team-based pedagogy (see Chapter 2). The mixture of civilian and military institutions provides a combination of a more traditional civilian undergraduate engineering experience at site A and mandatory, 4-year leadership programs at sites B and C. Leadership training for students at site A may include voluntary affiliation with purposeful leadership development through the Corps of Cadets for some students (the Corps of Cadets represents less than 5% of the ME students at site A) or various other voluntary leadership training programs. Mechanical engineering was specifically chosen because of the discipline's professional interest in engineering leadership (see ASME Center for Education, 2011), mechanical engineering's prominence as the largest discipline for bachelor's degree attainment (Yoder, 2014), and alignment with the researcher's career interests. The study had IRB approval at all three institutions.

The survey was administered by the authors on-line using Qualtrics survey development software at sites A and B. The office of institutional research at site C administered the online survey through a different web host. At all three sites participation in the survey was voluntary; students were recruited via a short introduction to the research by the capstone course coordinators in-class. At site B, the survey was attached to the course end's peer-review assignment but was identified as a separate research survey and not a course requirement.

This study's sample included 209 students (Table 4.1) who comprised 45 complete design teams; teams were only included if they exhibited a 100% response rate, which was a requirement for social network analysis. These 209 cases represent 46.5% of the total responses from the research sites. Site A had 118 participants (21 teams), site B had 58 participants (16 teams) and site C had 33 participants (8 teams). 10 of the 45 teams were student-identified sub-teams of larger capstone projects. Although all participants were engaged in mechanical engineering (ME) capstone design projects, 15 (7%) of the participants were non ME majors: 8 students (4%) were electrical engineering/computer science (EE/CS) majors, 3 were general engineering (GEN) majors (1%), and 4 were from other engineering disciplines (2%), (chemical engineering, civil/environmental engineering, and industrial/systems engineering). At Site A, 8 of the 118 students (7%) were members of the Corps of Cadets, and all students at sites B and C were military officers in training.

Table 4.1: Sample Demographics

Students†	Asian	Black	Hispanic	Native American	Pacific Islander	White	Multi-Race	Inter-national	Male	Female
209	6.7%	2.4%	7.2%	0.0%	0.0%	78.9%	4.8%	3.3%	90.9%	9.1%

†members of 45 complete design teams.

Although all team members in this sample completed surveys, 22 students (10.5% of the sample) submitted surveys with some incomplete items that were treated to maintain the team-level data. In total, these incomplete surveys only were missing 0.47% of all possible survey response items (164 total missing item responses). Of the 164, data were imputed for the five missing responses to non-dyadic survey items (e.g., sex identification or international status), conforming with the recommendations of Cox et al. (2014), using multiple imputation algorithms in SPSS. The remaining 159 missing dyadic responses to leadership ratings (i.e., team member rating of another team member) were imputed through a form of mean substitution. Other methods of imputation were not applicable because the participant response referenced an external individual rather than being generated internally (Huisman, 2009). Missing dyadic ratings were replaced by the mean rating of the rest of the team members regarding the rated individual.

4.4.2 Methods

4.4.2.1 Methods Overview

To address the two research questions, this study used a two-step analysis process to analyze team-level leadership data. For research question one, we used social network analysis of the TCR, MEA, and PA leadership scales that comprise the ME capstone version of the Full Range of Leadership model to determine a total of six team-level shared leadership measures. For research question two, we used separate cluster analysis of the teams based on each of the shared leadership measures (6 total cluster analyses) to determine team groupings that defined shared leadership quadrants for each of the three leadership scales. Figure 4.3 provides a graphical depiction of the study's methods.

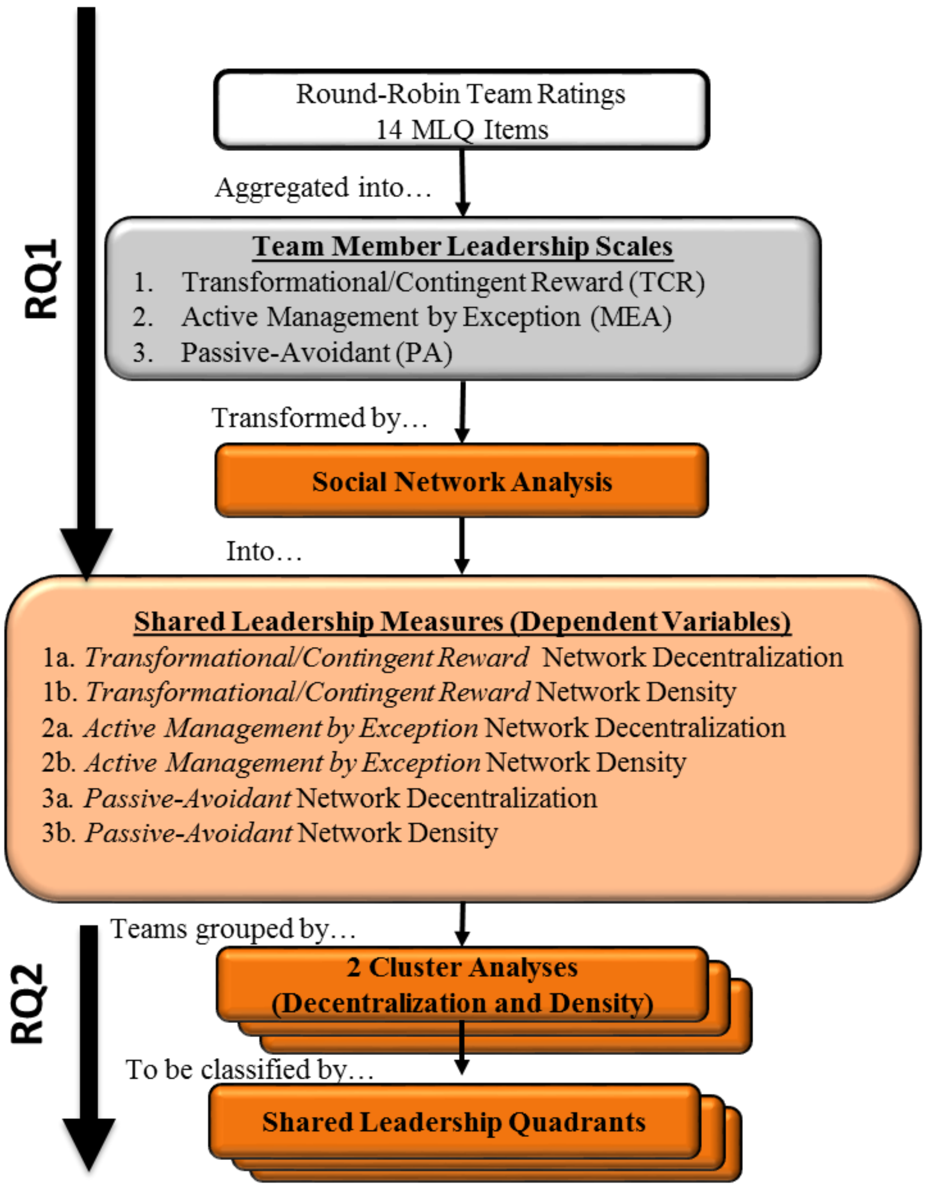


Figure 4.3. Research Methods Summary

4.4.2.2 Shared Leadership (Research Question 1)

Various meta-analyses have shown that shared leadership in teams is theorized as either 1) an aggregated, collective attribute existing across the team as a whole, or 2) a more complex sharing structure that emanates from the ebb and flow of dyadic (member to member) relationships across the team members (D'Innocenzo et al., 2014; Nicolaides et al., 2014; Wang et al., 2014). The majority of current shared leadership studies conceptualize shared leadership as the former—a team collective attribute (D'Innocenzo et al., 2014)—and correspondingly measure shared leadership using a *rate the team* approach (Gockel & Werth, 2010). By interpreting shared leadership as an aggregated team attribute, team members *rate the team* through a survey using direct-consensus (i.e., agreement among the members) or referent-shift consensus, where the referent becomes the team or the team members rather than the single external leader (D'Innocenzo et al., 2014; Gockel & Werth, 2010; Nicolaides et al., 2014; Wang et al., 2014). This approach to measuring shared leadership, however, fails to measure the distribution of leadership directly, but rather measures an average level of leadership across all team members (Gockel & Werth, 2010; Small & Rentsch, 2010). These types of studies are limited in their ability to fully understand how leadership is shared among team members (Small & Rentsch, 2010).

Thus, to operationalize shared leadership in this study, we used the latter interpretation—leadership is considered to be a network of dyadic relationships, which is often described as a *rate the members* approach (Gockel & Werth, 2010). In these types of studies, researchers use social network analysis of individual team member round-robin data (i.e., 360-degree data in which each member rates all other team members) (D'Innocenzo et al., 2014; Gockel & Werth, 2010; Nicolaides et al., 2014; Wang et al., 2014). Two measures of shared leadership are commonly used in this type of social network analysis: 1) network centralization (i.e., variability of individual indices), and 2) network density (i.e., proportion of influence relationships within the team compared to the total possible) (Gockel & Werth, 2010; Mayo et al., 2003). Mayo et al. (2003) proposed using this social network analysis approach across each scale of the Full Range of Leadership model to operationalize shared leadership in teams, which guides the design of this study.

4.4.2.2.1 NETWORK DECENTRALIZATION

The contributions of each individual member to the leadership network can be used to determine the degree to which leadership is distributed across the entire team. **Network centralization** provides a measure of cohesiveness of the network (Mayo et al., 2003), or the degree to which one member of the network "is holding all of the ties in that network" (Prell, 2012, p. 169). To determine network centralization, centralities are first calculated for each team member as the sum of all ties (i.e., leadership relationships for this study) attributed to that member by others. The centralization of the network is operationalized as the variance of these centralities. Mayo et al. (2003) present the network centralization calculation for a directed network (i.e. ties may exist in one direction but not the other), adapted from Freeman (1979) using Equation 4.1:

$$S_c^2 = \frac{[\sum_{i=1}^{g}(C_D(n^*) - C_D(n_i)]}{n^*(n-1)} \qquad [4.1]$$

In Equation 4.1, g is the total number of nodes in the network, $C_D(n_i)$ is the degree centrality of node n_i, and $C_D(n^*)$ is the maximum observed value. When calculating network centralization, only binary data are used to calculate a measure of centralization between zero and one, consistent with Freeman (1979).

Network centralization measures were transformed into decentralization measures in this study so that higher values correspond to higher degrees of shared leadership. Following recommendations of Gockel and Werth (2010), subtracting network centralization values from one produce a measure of **network decentralization**; a zero value represents individual leadership, and a one represents leadership that is fully distributed across the team (Gockel & Werth, 2010) (see depiction in Figure 4.4).

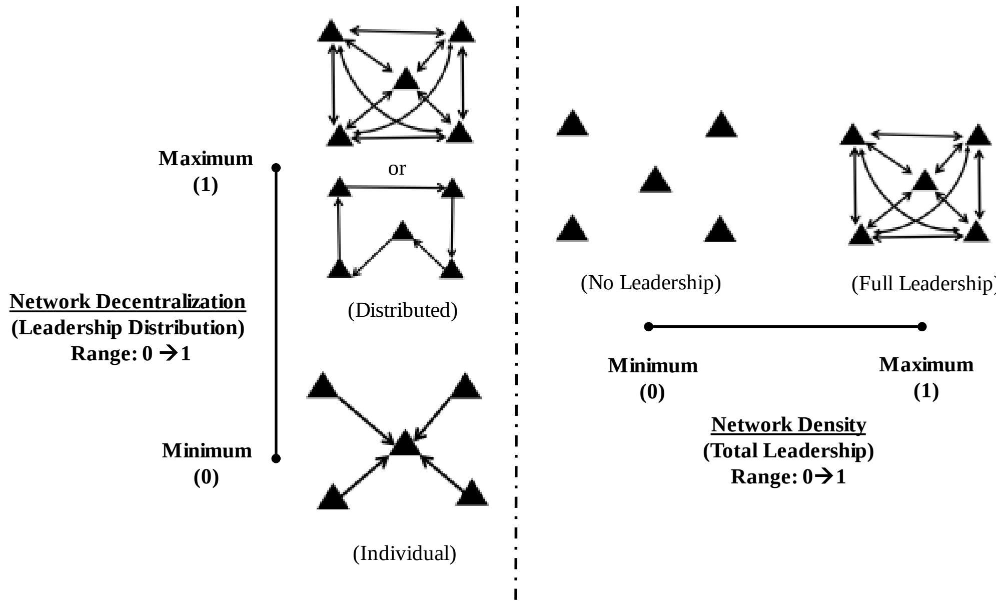


Figure 4.4. Shared leadership Measure Examples.

4.4.2.2.2 NETWORK DENSITY

One potential drawback to the network decentralization measure is the potential for deriving similar measures for extremely different networks. Teams with maximum distributed leadership can occur in any case in which all team members have an equal number of ties. In the diagrams representing maximum decentralization in Figure 4.4, each team member is tied to one other team member with a single tie in one example, and each member is tied to every other team member with a maximum number of ties in the other. One would argue that leadership in these two scenarios is drastically different. Thus, network decentralization only tells part of the leadership story.

To differentiate these two different leadership scenarios, Gockel and Werth (2010) and Mayo et al. (2003) recommend the inclusion of a **network density** measure in leadership network analysis, which indicates the total amount of leadership that is happening within the network. Network density compares the total number of social ties within a network to the total possible within the network. Prell (2012), provides an equation for calculating network density for a directed network (i.e., ties are directional) as:

$$D = \frac{L}{n(n-1)} \qquad [4.2]$$

In Equation 4.2, L is the total number of ties in the network and n is the number of nodes. The bottom of Figure 4.4 shows teams with minimum (0) and maximum (1) network density.

4.4.2.2.3 DECENTRALIZATION AND DENSITY AS SHARED LEADERSHIP

Using network density along with the network decentralization of the team, a complete accounting of shared leadership within the team can be ascertained as shown in the leadership quadrants depicted in Figure 4.5. Note that Figure 4.5 is similar to Figure 4.2 with a re-labeling of the axes. First proposed by Mayo et al. (2003), these four leadership quadrants depict how the measures of decentralization and density can differentiate levels of shared leadership and vertical leadership in teams.

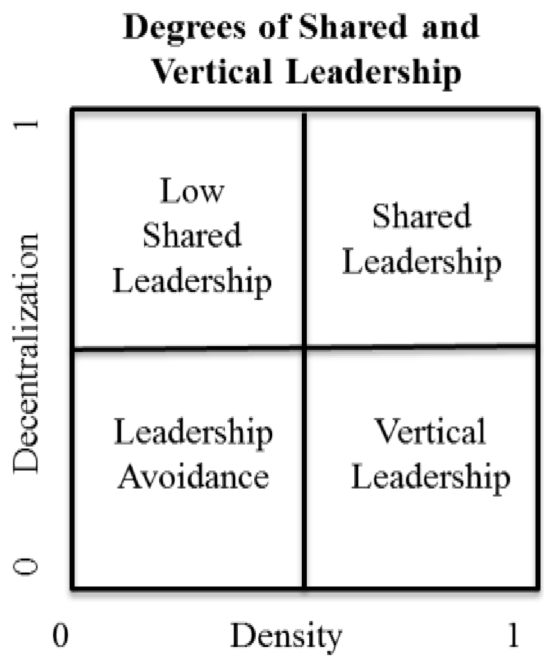
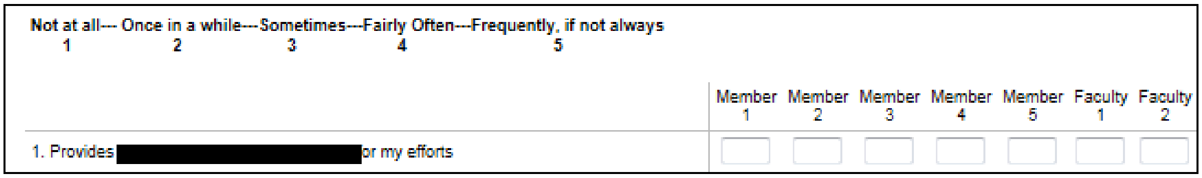


Figure 4.5. Classifying leadership by Decentralization and Density

4.4.2.2.4 ACCOUNTING FOR THE FULL RANGE OF LEADERSHIP

To consider leadership across a full range of behaviors in our *rate the members* approach to shared leadership, we used a 14-item subset of the MLQ (Form 5X) developed in Novoselich and Knight (2015).. Students were asked to rate their teammates and faculty advisor on these 14 leadership descriptive statements using a five point Likert-type scale: 1=Not at all; 2=Once in a while; 3=Sometimes; 4=Fairly Often; 5=Frequently if not always, in a round-robin fashion (See Figure 4.4).


Not at all--- Once in a while---Sometimes---Fairly Often---Frequently, if not always
1 2 3 4 5

	Member 1	Member 2	Member 3	Member 4	Member 5	Faculty 1	Faculty 2
1. Provides [redacted] or my efforts							

Figure 4.6. Sample Round-Robin Survey Item
(redacted because of copyright agreement).

The round-robin survey data provided by the students across the 14 items were partitioned into scale variables representing intra-team relationships in TCR, MEA, and PA leadership scales identified by Novoselich and Knight (2015; Chapter 3) (Table 4.2). To calculate the scale scores, leadership behavior ratings were averaged across all team members so that each team member and the faculty advisor had a team average leadership rating attributed to them for each scale.

Table 4.2: Leadership Scale Variables

Leadership Scale	**Leadership Factor**	**MLQ Item***	**Alpha**
Transformational/ Contingent Reward (TCR)	Individualized Concern	31	0.92
	Intellectual Stimulation	32	
	Inspirational Motivation	26	
	Contingent Reward	35	
	Idealized Influence (Behavior)	14	
	Idealized Influence (Attributed)	10	
Active Management by Exception (MEA)	Management by Exception (Active)	22	0.82
		27	
		4	
		24	
Passive-Avoidant (PA)	Laissez-Faire	5	0.88
	Management by Exception (Passive)	12	
		3	
	Laissez-Faire	7	

*Item text not included due to copyright agreement.

For this study, only strong leadership ties between members were considered, which provides a conservative measurement of shared leadership within the teams. Ties between team members were filtered such that a frequency rating less than or equal to three on the Likert-type scale (i.e., sometimes) was deemed too infrequent to be considered. Although a relationship may exist between team members with lower leadership behavior frequency ratings (i.e., below three), the infrequency of the leadership behaviors calls into question the degree of influence occurring between the team members. This filtering acknowledges a known social network analysis bias toward strong ties (see Prell, 2012) by purposefully focusing only on strong connections within the team and is similar to the cutoff scores used by Mayo et al. (2003) to create binary network data in their theoretical description of this social network research design.

Network analysis proceeded using the SNA package in R. The team member ratings across the three separate scales were analyzed to determine the network decentralization and network density for each of the three leadership networks. A total of six shared leadership measures resulted*:* 1) *TCR decentralization, 2) TCR density, 3) MEA decentralization, 4) MEA density, 5) PA decentralization,* and 6) *PA density*. Descriptive statistics of these measures indicated the degree to which leadership was shared within the design teams, addressing research question one.

4.4.2.3 Classification of Design Teams (Research Question 2)

Classifying teams based on their shared leadership was informed by the leadership quadrant methodology explained by Mayo et al. (2003). To classify teams based on their shared leadership, both measures of density and decentralization were considered. In their hypothesized study, Mayo et al. (2003) recommend classifying teams in one of four leadership quadrants based on the density and decentralization of the team's shared leadership measures (see Figure 4.5). Teams exhibiting high density and high decentralization measures are considered shared leadership teams (top/right), and teams exhibiting high density and low decentralization are considered vertical leadership teams (bottom/right). Teams with low density and decentralization are considered leadership avoidant teams (bottom/left), and teams with low density and high decentralization are considered low shared leadership teams (top/left). To fully account for the Full Range of Leadership, however, a single quadrant assignment was insufficient. Our study took this classification system a step further by categorizing teams with a shared leadership quadrant for each of the three forms of leadership investigated (TCR, MEA, and PA), resulting in a total of three shared leadership quadrant classifications for each team.

We examined the groupings of design teams based on each of the six measures of shared leadership to identify where leadership grouping boundaries occur. In their proposed study, Mayo et al. (2003) failed to articulate the actual values that quantified "high" and "low" decentralization and density to define leadership quadrants related to shared and vertical leadership. To address this empirical gap, we used six separate cluster analysis to define boundaries between groups of teams based on each of the six shared leadership measures. Cluster analysis is a statistical method that identifies homogenous groupings within a sample by of by maximizing between group variance and minimizing within group variance (Everitt, 2011; Steinley, 2006).

To perform the analysis, we used the TwoStep cluster component of SPSS version 23 (SPSS INC., 2001). This process includes a pre-cluster step that sequentially scans cases to create a series of potential clusters based on the specified distance criterion. A follow-on hierarchical clustering analysis determines the optimal number of clusters. In this follow-on analysis, these potential clusters are evaluated using the specified fit criterion to determine an initial estimate for the parsimonious number of clusters by minimizing the fit criterion. A final determination of the appropriate number of clusters is determined by evaluating the maximum distance between the two closest clusters. For our analyses, we used the Euclidean distance as our specified distance criterion consistent with Steinley (2006). We used Akaike's information criterion (AIC) as our specified fit criterion over the default Bayesian information criterion (BIC) to capitalize on AIC's propensity to over-estimate the number of parameters in cluster analysis (see Steinley, 2006). Evaluating the fit of the groupings to the team data provided evidence to support the suitability of a quadrant system for differentiating teams based on their level of shared or vertical leadership.

4.4.3 Limitations

Several limitations should be acknowledged when interpreting the results. First, this study focuses on the mechanical engineering capstone design context with senior-level engineering students at only three research sites. As a result, generality claims to the wider field of engineering across multiple disciplines, class years, and professional practice are unwarranted.

A second limitation of this study is the reduced number of MLQ items included in the survey. Although a full examination of all 36 MLQ leadership descriptive statements was desired, low student response rates in pilot data collection efforts prompted a decrease in survey length to help bolster survey response rates as discussed in (Novoselich & Knight, 2015). As a result, it is inappropriate to compare the specific findings of this study to those of other studies that incorporated all 36 MLQ leadership descriptive statements without acknowledging differences in data collection techniques employed. Mind Garden Inc., the copyright holder for the MLQ, asserts that administering only part of the survey may change the interpretation, and the validity properties of the instrument may change (Mind Garden, 2015). Novoselich and Knight (Chapter 3) acknowledge these concerns in their validation study.

Third, there are limitations inherent to the use of survey data. Survey responses require recollection of events which is subject to memory distortion over prolonged periods (Singleton & Straits, 2010). As raters of other team members' leadership behaviors, students may feel threatened by the survey process (Zafft et al., 2009). Although confidentiality of the survey data was ensured and explicitly stated in the recruiting and informed consent processes, students may not have fully trusted the process (Hurley, 1998), especially since the names of all team members were included on the team-specific surveys to ensure rating accuracy. Consequently, student ratings may have been inflated to be more socially acceptable (Singleton & Straits, 2010). The round-robin nature of the data collection process required for a *rating the members* approach to shared leadership is also time consuming and survey fatigue may set in, which could also result in inaccurate ratings (Grunspan, Wiggins, & Goodreau, 2014).

Finally, the study purposefully did not require faculty advisors to reciprocally rate team member leadership. This decision was made in an effort to maximize full-team response to data collection as interactions with various course coordinators and faculty advisors indicated the potential for low faculty member response rates. Full team responses were required to generate team level ratings of each team member and for follow-on social network analysis to measure leadership sharing. The exclusion of the advisor's rating of the team members is inconsistent with the norms of social network analyses, creating potential gaps in the leadership networks. This facet of the study design does, however, reflect the reality that students may not possess the expert or legitimate social power (see French & Raven, 1959; Pierro et al., 2013) with which to influence their faculty advisors through leadership actions.

4.5 Results and Discussion

4.5.1 Addressing Research Question 1: Shared Leadership in Teams

In addressing research question one, social network analysis results partially supported hypothesis 1. Across the six measures, leadership is more shared within the student design teams for four measures of the Full Range of Leadership. The extent to which shared leadership occurs was different among the various forms of leadership, however. Descriptive statistics for network decentralization and density shown in Table 4.3 indicate that the mean decentralization and mean density for TCR are high (i.e., greater than 0.5), placing these teams in the *shared leadership* quadrant of Figure 4.5. With a mean density value of 0.63 for TCR leadership shows that on average, almost two-thirds of a team's potential TCR leadership ties are occurring, making TCR leadership the only type of leadership classified as shared leadership.

Table 4.3: Leadership Variable Descriptive Statistics

	N	Minimum	Maximum	Mean[1,2]	Std. Deviation
TCR Network Decentralization	45	0.25	1.00	0.70	0.19
MEA Network Decentralization	45	0.22	0.94	0.75	0.15
PA Network Decentralization	45	0.25	1.00	0.84	0.19
TCR Network Density	45	0.25	0.80	0.63	0.14
MEA Network Density	45	0.05	0.67	0.35	0.13
PA Network Density	45	0.00	0.36	0.05	0.07

[1]For Decentralization: 1=shared leadership; 0=vertical leadership
[2]For Density: 1=full leadership; 0=no leadership

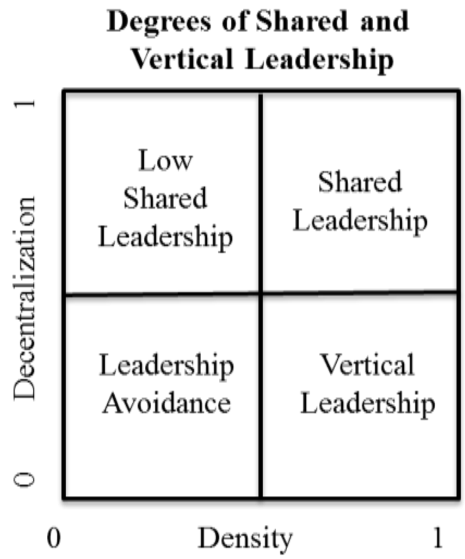


Figure 4.7. Leadership Quadrants; adapted from Mayo et al. (2003) [7]

For MEA, the high mean decentralization and lower density scores place teams in the *low shared leadership* quadrant of Figure 4.7, using 0.5 as the value for the separating value. Finally, for PA leadership, high mean decentralization and low mean density scores place teams in the *low shared leadership* quadrant of Figure 5 as well. With mean density scores of 0.35 and 0.05 for MEA and PA leadership respectively, slightly over one third of the MEA ties and about 5% of the PA ties occur more than sometimes (based on the Likert scale cutoff of three used in this study). Correspondingly, although leadership is shared across the breadth of the Full Range of Leadership (all three forms show high decentralization), the amount of shared leadership differs considerably across the three forms with TCR leadership distinguishing itself from MEA and PA.

Examination of the maximum and minimum density and decentralization values in Table 4.3 show that the 45 teams cover the breadth of shared and vertical leadership. The low network density minimum values for MEA and PA indicate that very little or none of these leadership behaviors are happening within some teams, placing them in the *low shared leadership* or *leadership avoidance* quadrants; maximum density values indicate that some teams do fall within in the *shared leadership* and *vertical leadership* quadrants

[7] This leadership quadrant figure from Mayo et al. (2003) is identical to that shown in Figure 4.5. The figure is brought forward in the text to assist the reader in referencing the quadrants for the remainder of the text.

of Figure 4.7. The decentralization minimum values indicate that some teams are more *leadership avoidance* or *vertical* in their leadership; maximum values indicated that other teams fall in the *low shared leadership* or *shared leadership* quadrants.

The prevalence of shared leadership practices across the design teams indicates that a shared leadership model may be an appropriate way to characterize leadership within engineering capstone design teams. These results corroborate the small sample findings of Zafft et al. (2009), as well as Feister et al. (2014) who articulated the shared, emergent nature of leadership within student design teams and Pearce (2004) who asserted that shared leadership is an effective model for knowledge work that is creative, complex, and interdependent. The sharing of leadership in design teams may also help explain the discomfort Rottmann et al. (2014) found between practicing engineers and traditional leadership actions. Engineers who see inconsistency between leadership and the collaborative nature of their profession may not be familiar with the relatively recent shared conceptualization of leadership, which this research shows is pervasive for student design teams.

These results also provide evidence that engineering students may lead each other in effective ways, as design teams exhibited high density TCR leadership networks. The wide body of literature regarding the Full Range of Leadership model indicates that transformational behaviors are the most active and often the most effective in a variety of contexts (Antonakis & House, 2013; Lowe, Kroeck, & Sivasubramaniam, 1996; Wang et al., 2011). Contingent reward behaviors are also among the most active and effective (Antonakis & House, 2013; Lowe et al., 1996; Wang et al., 2011). Both of these are components of the TCR leadership scale. Active management by exception has been shown to exhibit both positive and negative relationships with organizational effectiveness (Antonakis & House, 2013; Lowe et al., 1996), and Passive-avoidant behaviors are consistently negative predictors of effectiveness (Antonakis & House, 2013). On average, there was a greater number of ties in the more effective TCR leadership network than the less effective MEA and PA networks within the design teams of this study. Further research is warranted to determine the effectiveness of each form of leadership for undergraduate engineering design teams, as current literature fails to address this context (see Chapter 5).

4.5.2 Addressing Research Question 2: Team Classification

Cluster analysis results indicated that a leadership quadrant classification system may be appropriate for shared leadership within the design teams included in the sample—this analysis also demonstrated that the axes should not necessarily intersect at the 0.5 point along each scale to understand variation between teams. In conducting the cluster analyses of each shared network measure individually, five of the six analyses indicated that the shared leadership measure differentiated the teams into two groups. *TCR density* was the only exception. For *TCR density*, although the TwoStep clustering analyses indicated that three groupings were more appropriate, the third grouping incorporated only two of the 45 teams. Because such a small grouping is meaningless for subsequent statistical analyses, a second TwoStep cluster analysis was performed to specify two groupings. Results indicated good cluster quality using a silhouette coefficient analysis (see Kaufman & Rousseeuw, 1990; SPSS INC., 2014). Because measures of shared leadership identified only two groups per measure, a more complex classification system was deemed unwarranted.

By differentiating teams into two distinct groupings across each of the six measures of shared leadership, quadrant boundaries could be established for each of the three forms of leadership (Figure 4.8). The quadrant boundary locations shown in the three leadership quad charts indicated that high and low density and decentralization separation occurred at varying locations across the three forms of leadership. For the TCR network, the quadrant boundaries were more centrally located (0.44 and 0.60, respectively) than for the MEA network (0.33 and 0.65) and PA network (0.20 and 0.63). For MEA and PA leadership, the relatively low density of leadership across the teams yielded a markedly lower density boundary value than for TCR leadership.

Visualizing the leadership occurring in each quadrant demonstrates that even for low decentralization teams, leadership emanates from multiple team members. Figure 4.8 shows the associated leadership network diagram (i.e., "sociogram") for a representative team within each leadership quadrant. These sociograms allow a visualization of what leadership ‘looks like’ within those teams. In the sociograms, the triangles represent team members (orange) and the faculty advisor (yellow), and arrows represent dyadic (member to member) leadership relationships. The size of the triangle represents the relative centrality (i.e., prominence) of that person within that specific leadership network. These network diagrams demonstrate the complexity of leadership relationships within the teams. Even for low decentralization in which teams were classified as vertical leadership or leadership avoidance, multiple team members may enact leadership within the network because the decentralization values are all greater than zero.

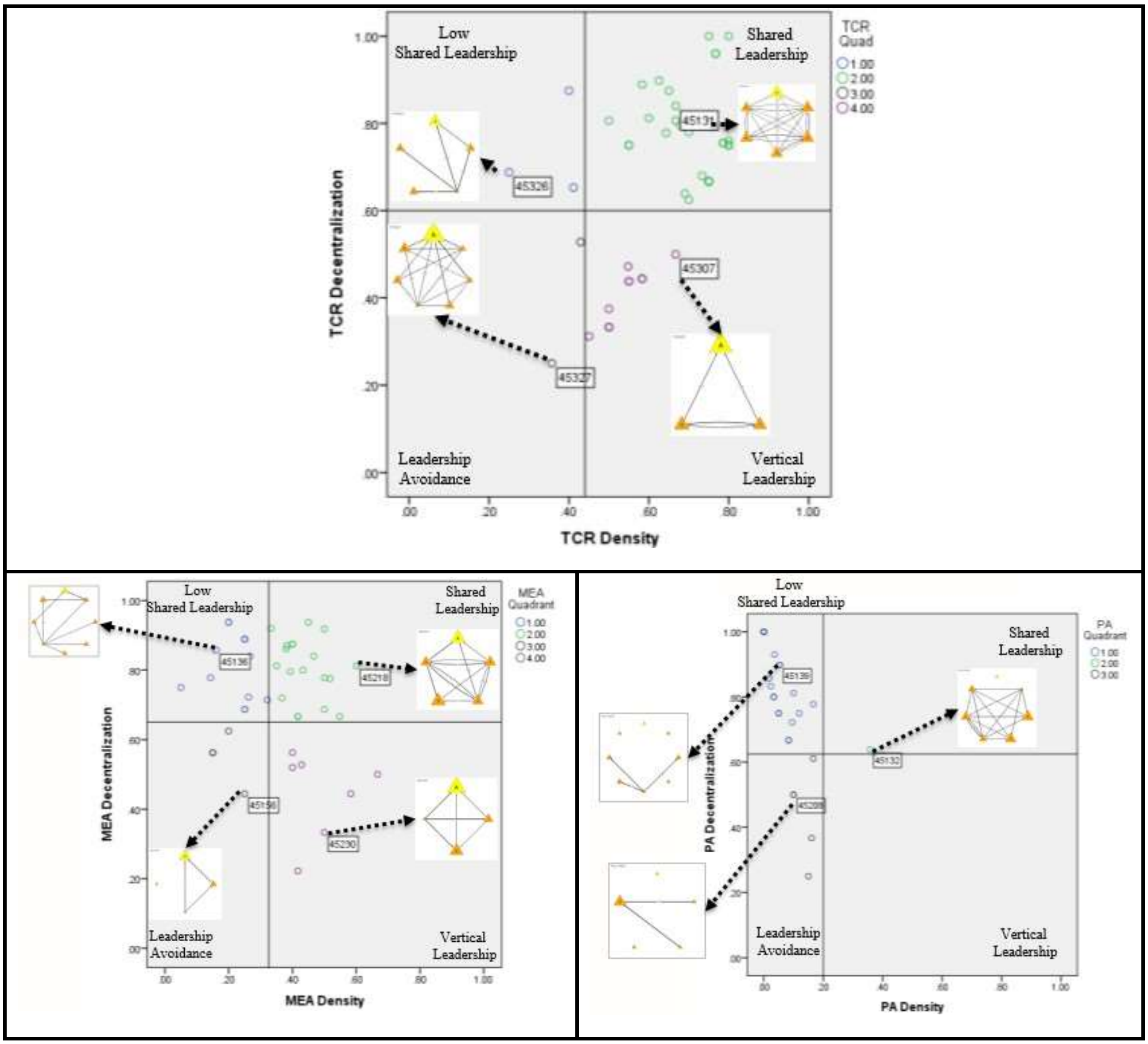


Figure 4.8: Team Leadership Quadrant Summary

Across the 12 different leadership quadrants established, teams provided representation in 11 of the 12. Only PA vertical leadership was not represented. For PA leadership, although cluster analyses were able to group teams based on each measure separately, high PA density teams all also had high PA decentralization, and low PA density teams were dispersed across the range of PA decentralization. As a result, when both boundaries were combined, no teams were represented by vertical PA leadership.

The number of teams assigned to each of the 12 leadership quadrants is summarized in Table 4.4. Summing the total number of teams accounted for in the low shared leadership and shared leadership quadrants (i.e., Total Shared), these results indicate that the majority of teams within the sample enact more shared leadership across the three forms rather than vertical leadership or leadership avoidance. These findings corroborate our results for research question one and the previous literature (Feister et al., 2014; Zafft et al., 2009) indicating that leadership is more shared than vertical in student design teams. An unanticipated finding was the dramatic difference in the amount of leadership that occurs across the three forms. High density scores characterized 40 of the 45 teams for TCR leadership (see High Density column of Table 4.4) which was more than the total shared leadership teams. For MEA and PA leadership, more teams were shared than high density. These results further indicate that much more TCR leadership occurs within the teams than either MEA or PA leadership.

Table 4.4: Leadership Quadrant Summary

	Low Shared Leadership	**Total Shared**	**Shared Leadership**	**High Density**	**Vertical Leadership**	**Leadership Avoidance**
TCR	3	3+30=33	30	30+10=40	10	2
MEA	15	15+19=34	19	19+7=26	7	4
PA	39	39+1=40	1	1+0=1	0	5

4.6 Implications

Several implications emerge from the results of this study. First, this study indicates that engineering educators should account for shared conceptualizations of leadership when working with undergraduate design teams; it appears as if leadership within student design teams may exhibit a greater degree of sharedness than historically vertical models, consistent with the assertions of Zafft et al. (2009) and Feister et al. (2014). The 45 design teams examined for this study exhibited a greater degree of shared than vertical leadership, on average, across all three of the leadership networks that comprise the Full Range of Leadership. As a consequence, faculty may consider the types of leadership frameworks they encourage within student design teams through tools such as team charters (Cox & Bobrowski, 2000; Hughston, 2014). Requiring teams to specify a team leader may cause frustration and confusion among students as they attempt to reconcile individual, vertical leadership concepts in a shared environment. Course documents may, more appropriately encourage identification of a team facilitator or team manager and acknowledge the potential for multiple leaders within a team. Solely individual models of leadership may inhibit potential sources of influence within the teams (Pearce, 2004). Team members may perceive that it is not their place to influence the team because of a lack of leadership positioning; additionally, students identified as leaders may fail to consider sources of influence from team members when holding a vertical leadership perspective. For engineering practitioners, these results provide a context for the leadership dynamic that these students experience in their last formative engineering project many will face prior to entering the profession.

Second, this research developed a leadership taxonomy which may help make complex leadership concepts accessible (Contractor et al., 2012) for students, engineering educators, and engineering education researchers. The taxonomy developed in this study encompasses not only multiple forms of leadership but also how those forms are shared within undergraduate engineering design teams. Illuminating the three separate forms of leadership behaviors for engineering students may make the often nebulous idea of leadership more concrete and nuanced towards their personal experiences in the capstone design space. Addressing the forms of leadership across the continuum for vertical to shared may allow them to better describe how leadership emanates from their team (Contractor et al., 2012; Mayo et al., 2003). By relating the three forms of leadership and types of shared leadership to concrete experiences, engineering students may gain a basic level of leadership knowledge that can then be applied and reflected upon increasingly throughout their careers, as the National Academy of Engineering (2004) aspires.

Third, this study demonstrates the complexity of how engineering students lead; engineering education researchers may consider the methodology by which they study leadership to ensure oversimplification of the phenomenon does not result. The social network analysis results indicate that leadership influence occurs in three conceptually different forms, to varying degrees, and should be considered at the dyadic level, consistent with the recommendations of Mayo et al. (2003) and Gockel and Werth (2010). Although a *rate the team* approach to team leadership study may be prominent in current shared leadership literature, this method may fail to examine comprehensively the complexity of leadership interaction that is occurring within the team which can be elucidated in a *rate the members* approach (Gockel & Werth, 2010). At a minimum, researchers should be aware of these limitations and consider them in developing their research design. More broadly, through an application of the *rate the members* approach to shared leadership research, this study demonstrates the utility of social network analysis in rendering the complexity of design team interactions in useful ways.

Finally, this study indicates the utility of social network analysis to both quantify and visualize complex, team-level phenomena. Visualizing shared leadership through social network analyses provided additional insights into the leadership networks that were not readily apparent through numerical description. Specifically, although low decentralization teams were characterized by vertical leadership, which may often be associated with a single, individual leader (Pearce & Conger, 2003b), an examination of network diagrams indicated that this was not actually the case for the design teams. Although decentralization values greater than zero indicate multiple team members enact leadership, being able to see what leadership 'looks like' in the network provided much needed insight that may have otherwise been overlooked. Although teams may enact vertical leadership, none of the teams attribute leadership behaviors to only one individual.

4.7 Conclusions and Future Work

This study demonstrates the utility of social network analysis in a *rate the members* approach for measuring shared leadership in the engineering design team context using a reduced set of MLQ items. Operationalizing shared leadership as a combination of network decentralization and density across three leadership networks, we found evidence to support its prevalence in mechanical engineering centric capstone design teams. The amount of leadership existing in the networks varies and is consistent with previous analyses of the Full Range of Leadership model in the student teaming literature. The teams were adequately represented by a shared leadership quadrant classification system, with at least one team falling in 11 of the 12 possible shared leadership quadrants.

Although the findings of research question one indicated the degree to which leadership is shared across the Full Range of Leadership, the effectiveness of the different forms of leadership was beyond the scope of this study. Further investigation is warranted to determine how sharing these forms of leadership, and combinations thereof, may contribute to enhanced learning for the engineering students and overall design team effectiveness. Although descriptions of the Full Range of Leadership model by Bass (1985) and Northouse (2013) may support transformational/contingent reward building upon active management by exception to produce team performance beyond expectations, empirical evidence is not currently available to support these assertions for capstone design teams. Further investigations that relate decentralization and density measures across the three leadership forms to measures of team success would provide empirical support for more and less effective models of team leadership and is an area of on-going research for the authors (see Chapter 5).

Additionally, further exploration of the dyadic leadership relationships occurring between team members is warranted to unpack the shared leadership phenomenon within the teams. The network data included in this study allows for exploration of the prominence that each team member, including the faculty advisor, holds in the leadership networks through measures of network centrality. Determining the personal attributes that relate to this emergence, for example, can help characterize leadership emergence from within the team.

Finally, this study focused exclusively on the mechanical engineering capstone design context. Although the study provides critical insights into how students share leadership in a key developmental experience prior to professional engineering practice, the study's focus on the mechanical engineering capstone design context prevents generalization across engineering disciplines and breadth of the undergraduate engineering experience. Further study is warranted within other engineering disciplines and across developmental stages from freshman year to professional practice to address the applicability of a shared leadership model to the larger practice of engineering.

Chapter 5

Manuscript 3: Is Sharing Leadership Effective? Relating shared leadership to team effectiveness and team attributes for mechanical engineering capstone design teams.

5.1 Abstract

Background

Multiple national-level reports have indicated the need for engineers to take more prominent leadership roles to better-inform complex policy decisions. Engineering faculty are tasked to develop a basic level of leadership knowledge within undergraduate engineering students that can then be applied increasingly throughout their careers. Recent engineering leadership literature, however suggests that an adequate model of how engineers lead in collaborative team-based environments does not exist. Several studies indicate that a shared leadership model may be more effective than the historically vertical models. Little empirical evidence is available to support these claims or determine what contributes to shared leadership development with design teams.

Purpose/Hypothesis

The purpose of this study is to further develop a model of how engineers lead in collaborative, team-based environments. This study hypothesizes that sharing leadership will positively relate to design team effectiveness and that specific team attributes will relate to the level of shared leadership in the teams.

Design/Methods

This quantitative study examines round-robin (360-degree) student leadership ratings gathered from mechanical engineering capstone design team students using a 14-item subset of the Multifactor Leadership Questionnaire. Shared leadership is operationalized as a combination of network decentralization and density using social network analyses across three forms of leadership related to the Full Range of Leadership model. These measures serve as independent variables for explanatory regression analyses examining relationships to multiple measures of team effectiveness. The measures also serve as dependent variables related to specific team attributes.

Results

Results indicates that the level of shared leadership within the team relates to the group process and individual satisfaction components of team effectiveness but did not relate to measures of task performance (i.e., course grades). A selection of team attributes, to include team engineering GPA, GPA diversity, team leadership skills, team size, and team sex related to various aspects of shared leadership within the teams.

Conclusions

This study expands an empirically tested model of how engineers lead for undergraduate engineering student design teams. The model adds greater depth to previous shared leadership literature claims that a shared leadership is a more effective model for knowledge work that is creative, complex, and interdependent. The model shows that an active, engaging form of leadership, distributed across a limited number of team members, may be more effective structure than fully shared or individual leadership structures. The model also shows specific team attributes that may relate to shared leadership development within the teams.

Key Words

Shared Leadership, Engineering Leadership, Team Effectiveness, Full Range of Leadership model, Multifactor Leadership Questionnaire, Social Network Analysis

5.2 Introduction

Since the publication of the Green Report (1994) more than two decades ago, reports from industry and the federal government have called for the preparation of engineering students with leadership skills (e.g., ASME Center for Education, 2011; National Academy of Engineering, 2004, 2005). Current reviews of engineering leadership education programs, however, indicate that engineering leadership programs largely lack institution resources (e.g., Graham, 2012). One potential barrier to progress in preparing engineers as leaders may be the view that leadership within engineering programs is best left to extra-curricular settings (Knight & Novoselich, 2014; Rottmann et al., 2014). Currently, leadership is not widely perceived as an integral skill in the development of students for the engineering field. A gap in literature may partially explain this perception that leadership is not integral to engineering practice. Recent literature suggests that an empirically tested model for effective leadership in a team-based engineering context does not exist (e.g., Paul & Cowe Falls, 2015; Reeve et al., 2015; Rottmann et al., 2014). Although conceptualizations of engineering leadership are departing from traditional, vertical views of leadership, there is no literature that describes how leadership relates to design team effectiveness or what team attributes relate to the way engineers lead their peers.

This study aims to address this literature gap by investigating leadership from the perspective of the collaborative, team-based environment that engineers routinely experience. Leadership scholars indicate that *shared leadership*, characterized by the serial emergence of official as well as unofficial leaders, may be a more effective model than a vertical, individualistic approach (Feister et al., 2014; Pearce, 2004; Pearce & Conger, 2003b), especially for the creative, complex, and interdependent knowledge work like that of an engineering design team. Although studies suggest that shared leadership is pervasive in undergraduate engineering design teams (e.g., Feister et al., 2014; Novoselich and Knight, Chapter 4), little is known regarding the effectiveness of shared leadership for design teams or how the level of shared leadership relates to the team itself. Building upon the prior shared leadership research of Novoselich and Knight (Chapter 4), this study deepens our understanding of shared leadership in design teams by examining how sharing various forms of leadership relates to team effectiveness; it also explores how team level attributes relate to the level of shared leadership in the team. Specifically, the study addresses the following research questions:

RQ1. How does the degree of shared leadership across the Full Range of Leadership relate to undergraduate mechanical engineering-centric capstone design team effectiveness?

RQ2. How do team-level attributes relate to the degree of shared leadership in undergraduate mechanical engineering-centric capstone design teams?

5.3 Review of the Literature

5.3.1 Effectiveness of Shared Leadership (RQ1)

Leadership literature has traditionally focused on vertical conceptualizations of leadership where one leader influences followers (Jackson & Parry, 2011; Markham, 2012; Pearce & Conger, 2003b). The possibility of multiple team members influencing each other has been a relatively recent development in the long history of leadership research (Pearce & Conger, 2003b). In the shared leadership paradigm, leaders emerge from the group based on their knowledge, skills, or ability, to lead the team through tasks or challenges and then pass the mantle of leadership to others as the team's situation evolves.

Shared leadership's rise accounts for the situated nature of knowledge; in this modern age of increased technology and rapid industrial pace, it is nearly impossible for one person to have the necessary knowledge, skills, and abilities for all aspects of highly intellectual work (Pearce, 2004). This scenario aligns with Newstetter's (1998) description of student learning environments in engineering design teams as well as Salas et al.'s (2007) integrative model of team effectiveness, which references team leaders (plural) not team leader (singular) and describes how shared cognition affects leadership and vice-versa. In light of this evolving knowledge distribution, Wageman and Gardner (2012) call for a re-examination of team leadership in light of the new landscape of modern collaboration. These calls are echoed by Dorst (2008), who calls for an examination of the context by which design is practiced, which are aims of this study.

Capstone design teams provides a suitable context for exploring how engineers lead. Capstone design projects are often a culminating, team-based event for undergraduate engineers as they prepare for professional engineering practice (Howe & Wilbarger, 2006). On the cusp of professional engineering practice, these experiences are also a final opportunity to address and develop engineering professional skills, to include leadership (Farr & Brazil, 2012; Shuman, Besterfield-Sacre, & Mcgourty, 2005). Pearce (2004) hypothesizes the positive role shared leadership can play in knowledge work that is creative, complex and interdependent, such as that of a design project. Cox et al. (2003) discuss the potential for shared leadership to benefit new product development team performance, a work atmosphere very similar to what is asked of capstone design students.

Limited empirical work suggests the effectiveness of shared leadership for the design team context. For student design teams specifically, Zafft et al. (2009) were able to establish that increased dispersion of different leadership profiles across team members related positively to team success in terms of course grades using the Competing Values Framework. The authors of this study admit, however, that they were unable to relate a specific measure of shared leadership to team success, which is a goal of this study. In other contexts, shared leadership has been shown to relate significantly to team outcomes. For example, recent meta-analyses of shared leadership indicate that both the distribution and quantity of leadership in teams positively relates to team effectiveness (Wang et al., 2014) and team performance (D'Innocenzo et al., 2014; Nicolaides et al., 2014). In light of this literature, we propose the following:

Hypothesis 1: Shared leadership positively relates to team effectiveness for mechanical engineering-centric capstone design teams.

5.3.2 Effective Forms of Leadership

The Full Range of Leadership model informs this study’s investigation of shared leadership. Whereas shared leadership examines how many individuals enact leadership within the teams, the Full Range of Leadership model explains how individuals perform different forms of leadership. The Full Range of Leadership model has been in existence for over two decades (see Bass & Avolio, 1994). Previous literature has demonstrated the applicability of the Full Range of Leadership model for engineering contexts (e.g., Breaux, 2006; Novoselich & Knight, 2015), and links between the theory and leadership orientations within engineering professional practice have been proposed by Rottmann et al. (2014).

Novoselich and Knight (2015) identified for the capstone design context three leadership scales conceptually similar to the original model: transformational/contingent reward (TCR), active management by exception (MEA) and passive-avoidant (PA). These scales are similar to those Avolio et al. (2003) conclude may constitute a parsimonious model of leadership in teams. Other research has also addressed similar scales (e.g., Avolio et al., 1999; Boies et al., 2010). Table 5.1 describes each.

Table 5.1: ME Capstone version of the Full Range of Leadership descriptions.

Form of Leadership	**Description**
Transformational/ Contingent Reward (TCR)	Developing team member strengths, maintaining a compelling vision, showing strong sense of purpose, and instilling pride in team members for being associated with those enacting leadership (Novoselich & Knight, Chapter 3)
Active Management by Exception (MEA)	Primarily utilizes negative reinforcement, having a consistent focus on maintaining standards in addition to identifying and tracking mistakes among team members (Antonakis & House, 2013; Novoselich & Knight, Chapter 3; Avolio, 2011)
Passive Avoidant (PA)	A delay in action until serious issues arise or a total absence of involvement, especially when needed (Avolio et al., 1999; Novoselich & Knight, Chapter 3).

The wide body of literature regarding the Full Range of Leadership model indicates the effectiveness of each form of leadership, but this research has not yet focused on the engineering design team context. The components of TCR leadership the most active and most effective in a variety of contexts (Antonakis & House, 2013; Lowe et al., 1996; Wang et al., 2011) indicating that this trend may also be true for design teams. MEA has been shown to exhibit both positive and negative relationships with organizational and team effectiveness (Antonakis & House, 2013; Lowe et al., 1996); for engineering design teams, these behaviors showed positive correlation with TCR leadership (Novoselich & Knight, Chapter 3), indicating the potential for MEA leadership to relate positively with effectiveness in the engineering design team context. Passive-avoidant behaviors are consistently negative predictors of effectiveness (Antonakis & House, 2013). Thus, we refine our first hypothesis:

Hypothesis 1A: The degree of shared TCR and MEA leadership will positively relate to team effectiveness.

Hypothesis 1B: The degree of shared PA leadership will negatively relate to team effectiveness.

5.3.3 Team Level Attributes Related to Shared Leadership (RQ2)

Although there is literature to support how sharing the various forms of leadership may relate to team effectiveness (i.e. Wang et al., 2014), much less is known regarding how team attributes may relate to shared leadership (Hoch, 2014). A better understanding of how various team attributes relate to the level of shared leadership within teams may provide engineering educators who structure and mentor design teams an additional resource to foster team effectiveness by understanding how the makeup of the team relates to the level of shared leadership then enact. In their development of a shared leadership model for new product development teams (a context similar to a student design team), Cox et al. (2003) hypothesized that certain team characteristics, including team member proximity, team size, team ability, team diversity (across multiple dimensions including race, gender, employment tenure, and educational backgrounds), and maturity, may relate to shared leadership. Limited studies have begun to investigate these hypotheses (i.e., Allen & O'Neill, 2015; Carson, Tesluk, & Marrone, 2007; Hoch, 2014; Mathieu, D'Innocenzo, et al., 2015), but the proposed hypotheses remain largely untested (Hoch, 2014). Correspondingly, the work of Cox et al. (2003), provides a foundation for the generation of hypotheses in the present study. The sections that follow propose a series of hypotheses based on that research as well as related literature.

5.3.3.1 Shared Leadership and Engineering Course GPA

Students' course performance within engineering may be related to shared leadership within the teams. Consistent with explanations of personal social power, (see French & Raven, 1959; Pierro et al., 2013) elevated academic ability within engineering may provide a source of social power for students to influence their peers and exercise leadership. Tonso (2007) echoes this interpretation in her ethnographic study of student design teams. She found that students with high academic-science expertise, as indicated by engineering science course performance, were afforded additional agency over their peers with less engineering science-expertise (Tonso, 2007). Thus, there is the potential for teams with a greater level of overall engineering course GPA to share leadership more actively because of their elevated, collective technical ability.

Correspondingly, because TCR and MEA are both active forms of leadership involving interactions with team members, these forms of leadership may be more prevalent when the collective GPA in the team is higher. Conversely, because PA leadership involves an absence of leadership behaviors, this form of leadership may be less prevalent in teams with elevated average GPAs. Cox et al. (2003) support these claims as they hypothesize positive relationships between team technical ability and shared leadership development for new product development teams. Accordingly, we hypothesize:

Hypothesis 2: Team average self-reported engineering course GPA will have a positive relationship with shared TCR and MEA leadership and a negative relationship with shared PA leadership.

In contrast, teams with a more diverse representation of engineering course GPA may exhibit more individualized leadership, as the higher GPA students are afforded additional agency with which to influence their teammates, similar to a technical mastery orientation of engineering leadership discussed by Rottmann et al. (2014). These relationships would hold across the three modes of leadership in the Full Range of Leadership (i.e., TCR, MEA, and PA), as disparity of agency among team members would result in a greater ability to enact TCR and MEA leadership for those with higher GPA, and greater PA leadership for those with lower GPA. These assertions result in the following hypothesis:

Hypothesis 3: Teams' self-reported engineering course GPA diversity will have a negative relationship with shared TCR, MEA, and PA leadership.

5.3.3.2 Shared Leadership and Team Size

Team size has also been hypothesized to have an effect on shared leadership, as Cox et al. (2003) propose a negative relationship between team size and shared leadership development. They suggest that as teams become increasingly large, close working relationships that lead to influence between team members will be more challenging to develop. Meta-analytic studies of shared leadership (e.g., D'Innocenzo et al., 2014; Nicolaides et al., 2014), however, indicate that team size is often relegated to a control variable, so confirming these propositions remains elusive. Increased group size has been shown to have a demotivating effect on its members, a phenomenon called social loafing (Borrego, Karlin, et al., 2013; Karau & Williams, 1993). Correspondingly, team members of larger teams may contribute less effort to the project, resulting in a decrease of shared TCR and MEA leadership. Conversely, larger teams may increase PA's absentee leadership behaviors, thereby increasing shared PA leadership. Thus, we hypothesize:

Hypothesis 4: Team size will have a negative relationship with shared TCR and MEA leadership and a positive relationship with shared PA leadership.

5.3.3.3 Shared Leadership and Leadership Skills

Students' individual perceived leadership abilities and the self-efficacy that entails may influence shared leadership within the teams. Bandura (1982) asserted that how individuals judge their capabilities affects their self-perceptions of efficacy and in turn their motivations and behaviors. Those with higher judgement of an ability (e.g., leadership) often rise to the demands of a situation more often than their lower judging counterparts (Bandura, 1982). Leadership self-efficacy involves a person's self-confidence in their ability to perform behaviors related to their leadership role (Paglis, 2010). Hence, students who rate themselves higher in engineering leadership skills may have higher leadership self-efficacy and, in-turn, may exhibit more leadership behaviors within a team. Correspondingly, for TCR and MEA, as forms of leadership requiring action, teams with greater average leadership skills would facilitate greater practice of these forms of leadership among its members, thus increasing shared leadership. Conversely, by measuring leadership inaction, PA leadership behaviors would be less present in higher leadership-skilled teams, decreasing shared leadership. Accordingly, we hypothesize:

Hypothesis 5: The average level of leadership skills within the team will positively relate to shared TCR and MEA leadership and negatively relate to shared PA leadership.

Leadership self-efficacy has also been shown to relate to individual leader emergence in teams. In their study of leader emergence from leaderless, all-male student groups, Smith and Foti (1998) found a strong correlation between general self-efficacy and leader emergence. Similarly, Paglis (2010) found positive relationships between individual leadership self-efficacy and leader performance. Consequently, teams with higher individual maximum leadership skills (i.e., one particular standout team member) may be more apt to exhibit vertical leadership as opposed to shared leadership; individuals with the highest leadership self-efficacy may emerge as a central, vertical leader within a team. Emergence of a central leader in the team would correspondingly diminish shared TCR and MEA leadership while increasing the shared PA behaviors of those team members not recognized as that central leader. Thus we hypothesize:

Hypothesis 6: The maximum individual leadership score within a team will negatively relate to shared TCR and MEA leadership and positively relate to shared PA leadership.

5.3.3.4 Shared Leadership and Sex

Literature supports potential relationships between leadership and personal characteristics. Carter, Mossholder, Feild, and Armenakis (2014) discuss how demographic characteristics, such as sex, may invoke social categorization in leader-follower situations. Although research indicates that little if any sex-related differences exist in overall leadership style or effectiveness (e.g., Hoyt, 2013), studies indicate that women emerge (Kolb, 1999; Lucas & Baxter, 2012), are perceived (Eagly & Karau, 2002; Lucas & Baxter, 2012), and are rated (Eagly & Karau, 2002) as leaders in ways that are distinguishable from men. Despite literature hypothesizing the benefits of shared leadership to close gender inequality in leadership roles (Neubert & Taggar, 2004; Pearce & Conger, 2003a), emerging research indicates that men emerge as leaders more often than women, even in shared leadership environments (Mendez & Busenbark, 2015). According to role congruity theory, women's leadership actions are typically perceived as influential, but only when it conforms to the social expectations ascribed to women in general, which tend to be more caring and communal (Eagly & Karau, 2002). Meta-analyses support these societal norms, showing that although differences are small, women tend to engage in more transformational and contingent reward and less in management by exception and laissez-faire leadership behaviors than their male counterparts (Eagly, Johannesen-Schmidt, & van Engen, 2003; Vinkenburg, van Engen, Eagly, & Johannesen-Schmidt, 2011). Correspondingly, women would be more likely to be recognized as leaders in a team's TCR network, which espouses behaviors that tend to be ascribed to women (Eagly et al., 2003), thus increasing the level of shared TCR leadership as the proportionality of women of a team increases. MEA or PA networks, which may be perceived as more masculine (Eagly et al., 2003), would correspondingly see a decrease in the number of recognized participants for teams with additional women, decreasing shared leadership. Accordingly, we hypothesize:

Hypothesis 7: The proportion of women assigned to a design team will have positive relationships with shared TCR leadership and negative relationships with shared MEA and PA leadership.

5.3.3.5 Shared Leadership and Race/Ethnicity

Research also indicates that race and ethnicity may relate to shared leadership, although the presence of these relationships varies by methods used. Dugan, Kodama, and Gebhardt (2012) summarize contradictory findings, with qualitative approaches suggesting that race influences student perceptions of leadership and leadership development (Arminio et al., 2000; Komives, Owen, Longerbeam, Mainella, & Osteen, 2005; Renn & Ozaki, 2010) and quantitative approaches showing little or no significant relationships (e.g., Cress, Astin, Zimmerman–Oster, & Burkhardt, 2001; Dugan & Komives, 2010; Posner, 2004). Seers, Keller, and Wilkerson (2003) argue that demographic differences may be a barrier to shared leadership when teams are comprised mainly of white males, which is common for current engineering teams. Limited research also suggests that Asian and Asian American students in particular may develop leadership differently than students of other races (Chung, 2014). Traditionally attributed to cultural norms of reserve and harmony in relationships (Fukuyama & Greenfield, 1983), research has shown that Asian Americans may struggle with being identified as leaders within a traditionally western culture (Chung, 2014). Kodama, McEwen, Liang, and Lee (2001) assert that "traditional Asian values" (p. 414), such as interdependence with family and deference to authority, may affect the college experience of these students. Cox et al. (2003) also hypothesize negative relationships for a series of diversity related attributes, including race and ethnicity, but these relationships have not been empirically tested. In light of these potential racial and ethnicity relationships, we hypothesize:

Hypothesis 8: Racial and ethnic diversity on a team will have a negative relationship with shared leadership development.

5.3.3.6 Shared Leadership and Project Effort

Team member project effort may also relate to shared leadership. Leaders are often characterized by hard work (Hogan & Kaiser, 2005) and set an example of hard work (Avolio et al., 1991). Manager effort has shown positive relationships with member perceptions of relationship quality in studies of leader-member exchange theory (LMX) (e.g., Maslyn & Uhl-Bien, 2001). Additionally, team members who exert a large amount of effort in a project may be perceived as more dependable or conscientious, which positively relates to leadership (Jackson & Parry, 2011; Northouse, 2013). As the team members across the team exert a greater amount of effort, there may be a corresponding increase in the number of team members perceived as leaders within the team and an increase in leadership interactions occurring within the team. Because TCR and MEA leadership both measure leadership actions, these forms of leadership would tend to be more shared with increased project effort, and PA leadership, which measures leader inaction, would correspondingly be less shared. We hypothesize:

Hypothesis 9: Average team level effort will have a positive relationship with shared TCR and MEA leadership and a negative relationship with shared PA leadership.

5.3.3.7 Shared Leadership and Engineering Discipline

Despite a dearth of research regarding engineering discipline differences in leadership actions, the literature indicates a potential for shared leadership to be related to the diversity of engineering disciplines in a team. While functioning on interdisciplinary teams, students' engineering disciplines may play a role in their ability to influence their teammates because of technical expertise. Disciplinary knowledge from an under-represented discipline within the team may provide a source of power for students to influence their peers and hence exercise leadership. For example, a mechanical engineering project with a complex circuit design aspect may include an electrical engineering student as a part of the team. As a subject matter expert in circuit design, the electrical engineering student may have significant influence on the project because of his or her expertise. Within explanations of personal social power (e.g., French & Raven, 1959; Pierro et al., 2013), expert power is attributed by followers to someone exhibiting competence in a subject area. In addition to this potential relationship, Knight and Novoselich (2014) found disciplinary differences in the perceptions of leadership importance in their study of undergraduate engineering program faculty and administrators which may filter down to students. These studies indicate that as the number of engineering disciplines represented in a design team increase, more students are afforded the ability to influence other team members, increasing the level of shared leadership. These positive relationships would hold true for both TCR and MEA leadership, which involve active influence of team members by the leader. The opposite relationship would hold to PA leadership, which is a measure of leadership inaction. In light of this literature, we hypothesize:

Hypothesis 10: Team engineering discipline diversity will have a positive relationship with shared TCR and MEA leadership and a negative relationship shared PA leadership.

5.3.3.8 Shared Leadership and Team Tenure

The amount of time team members have worked together (i.e., team tenure) may also relate to differences in shared leadership within the teams. Studies indicate that shared leadership takes time to develop as team member roles solidify and a history of interactions is built (e.g., Avolio et al., 1996; Avolio et al., 2003; Small & Rentsch, 2010) and that shared leadership is related to team tenure (Hoch, 2014). Students who have worked together for a longer duration in the past may be more apt to share leadership among themselves in current projects because of an increase in cohesion and shared values that has developed over time (Michel & Hambrick, 1992). Thus, previous work experiences may afford students the ability to more quickly generate close working relationships that can lead to shared TCR and MEA leadership, and decreasing the levels of shared PA leadership within the teams. From this body of literature, we hypothesize:

Hypothesis 11: The amount of time team members have worked together prior to the current project will positively relate to shared TCR and MEA leadership and negatively relate to shared PA leadership.

5.3.4 Summary of Hypotheses

Table 5.2 summarizes this study's hypotheses. For the hypotheses that relate team attributes to shared leadership (RQ2), the anticipated relationship between the team attribute and measures of shared leadership are expressed by '+' for a positive relationship and '-' for a negative relationship.

Table 5.2: Summary of Hypotheses

Research Question 1 Hypotheses				
		Relationship Direction		
		TCR	MEA	PA
***Hypothesis 1A**: The degree of shared TCR and MEA leadership will positively relate to team effectiveness.*		+	+	
***Hypothesis 1B:** The degree of shared PA leadership will negatively relate to team effectiveness.*				-
		Relationship Direction		
Attribute	Research Question 2 Hypotheses	TCR	MEA	PA
Team Eng. GPA	***Hypothesis 2:** Team average self-reported engineering course GPA will have a positive relationship with shared TCR and MEA leadership and a corresponding negative relationship with shared PA leadership.*	+	+	-
Eng. GPA Diversity	***Hypothesis 3:** Teams self-reported engineering course GPA diversity will have a negative relationship with shared TCR, MEA, and PA leadership.*	-	-	-
Team Size	***Hypothesis 4:** Team size will have a negative relationship with shared TCR and MEA leadership and a positive relationship with shared PA leadership.*	-	-	+
Team Leadership Skills	***Hypothesis 5:** The average level of leadership skills within the team will positively relate to shared TCR and MEA leadership and negatively relate to shared PA Leadership.*	+	+	-
Max Leadership	***Hypothesis 6:** The maximum individual leadership score within a team will negatively relate to shared TCR and MEA leadership and positively relate to shared PA leadership.*	-	-	+
Team Sex	***Hypothesis 7:** The proportion of women assigned to a design team will have positive relationships with shared TCR leadership and negative relationships with shared MEA and PA leadership.*	+	-	-
Racial/ Ethnic Diversity	***Hypothesis 8:** Racial and ethnic diversity on a team will have a negative relationship with shared leadership development.*	-	-	-
Team Effort	***Hypothesis 9:** Team level effort will have a positive relationship with shared TCR and MEA leadership and a negative relationship with shared PA leadership.*	+	+	-
Eng. Discipline Diversity	***Hypothesis 10:** Team engineering discipline diversity will have a positive relationship with shared TCR and MEA leadership and a negative relationship shared PA leadership.*	+	+	-
Team Tenure	***Hypothesis 11:** The amount of time team members have worked together prior to the current project will positively relate to shared TCR and MEA leadership and negatively relate to shared PA leadership.*	+	+	-

5.4 Data and Methods

5.4.1 Data Collection

Student surveys administered during the spring semester of the 2014–2015 academic year comprise this study's data. Participants were enrolled in year-long, team-based, mechanical engineering-centric, senior level capstone design courses at three institutions: a large, mid-Atlantic research university (site A) and two smaller engineering-focused military institutions (sites B and C). These study sites were purposefully chosen because of their historic leadership focus, ABET accredited engineering programs, comparable capstone design experiences, and access to participants. Qualitative comparison of course syllabi and team charter requirements across the three institutions indicated similarity in the capstone design experience with regard to course objectives, course content, project requirements, and team-based pedagogy (see Chapter 2). The mixture of civilian and military institutions provides a combination of a more traditional civilian undergraduate engineering experience at site A and mandatory, 4-year leadership programs at sites B and C. Leadership training for students at site A may include voluntary affiliation with the Corps of Cadets, which includes purposeful leadership development, or various other voluntary leadership training programs; the Corps of Cadets represents less than 5% of the participating ME students at site A. Mechanical engineering was chosen because of the discipline's professional interest in engineering leadership (see ASME Center for Education, 2011), mechanical engineering's prominence as the largest discipline for bachelor's degree attainment (Yoder, 2014), and alignment with the researcher's career interests. The study had IRB approval at all three institutions.

In taking the survey, team members assessed each of their teammates' leadership behaviors based on 14 MLQ-derived leadership descriptive statements (see Novoselich & Knight, 2015). These survey items were presented in a round-robin (360-degree) format, which asked all team members to rate each of their team members and the faculty advisor (Figure 5.2). A series of additional round-robin questions asked team members to rate their teammates and advisor regarding various MLQ derived leadership outcomes that related to team effectiveness. Finally, several individual questions regarding demographic information were also asked. The survey was administered by the authors online using Qualtrics survey development software at sites A and B, and the office of institutional research at site C administered the online survey through a different web host.

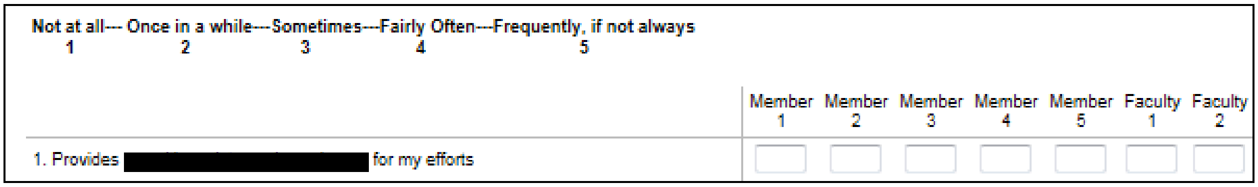


Figure 5.1 Sample Round-Robin Survey Item
(Item redacted because of copyright agreements)

This study examined the responses from 209 students (Table 5.3) who comprised 45 complete design teams, selected based on a team-level 100% response rate which was required for social network analysis. These 209 cases represent 46.5% of the total responses from the research sites. Site A had 118 participants (21 teams), site B had 58 participants (16 teams) and site C had 33 participants (8 teams). 10 of the 45 teams were student-identified sub-teams of larger capstone projects. Although all participants were participating in mechanical engineering (ME) capstone design projects, 15 (7%) of the participants were non ME majors; 8 students (4%) were electrical engineering/computer science majors (EE/CS), 3 were general engineering majors (GEN) (1%), and 4 were from other engineering disciplines (2%), (chemical engineering, civil/environmental engineering, and industrial/systems engineering), hence the mechanical engineering-centric team label. At Site A, 8 of the 118 students (7%) were members of the Corps of Cadets, and all students at sites B and C were military officers in training.

Table 5.3: Sample Demographics

Students†	**Asian**	**Black**	**Hispanic**	**Native American**	**Pacific Islander**	**White**	**Multi-Race**	**Inter-national**	**Male**	**Female**
209	6.7%	2.4%	7.2%	0.0%	0.0%	78.9%	4.8%	3.3%	90.9%	9.1%

†members of 45 complete design teams.

Although all team members in this sample completed surveys, 22 students (10.5% of the sample) submitted surveys with some incomplete items that were treated to maintain the team-level data. In total, these incomplete surveys only were missing 0.47% of all possible survey response items (164 total missing item responses). Of the 164, data were imputed for the five missing responses to non-dyadic survey items (e.g., sex identification or international status), conforming with the recommendations of Cox et al. (2014), using multiple imputation algorithms in SPSS. The remaining 159 missing dyadic responses to leadership ratings (i.e., team member rating of another team member) were imputed through a form of mean substitution. Other methods of imputation were not applicable because the participant response referenced an external individual rather than being generated internally (Huisman, 2009). Missing dyadic ratings were replaced by the mean rating of the rest of the team members regarding the rated individual.

5.4.2 Methods

5.4.2.1 Methods Overview

Figure 5.3 provides an overview of methods for this study. To address the two research questions, this study used a two-step analysis process to analyze team-level leadership data. For research question one, regression analyses related a total of six measures of shared leadership to measures of team effectiveness. Novoselich and Knight (Chapter 4) describes the derivation of those six shared leadership measures. For research question two, a combination of hierarchical linear modeling (HLM) and ordinary least squares (OLS) regression analyses related team attributes to the six measures of shared leadership.

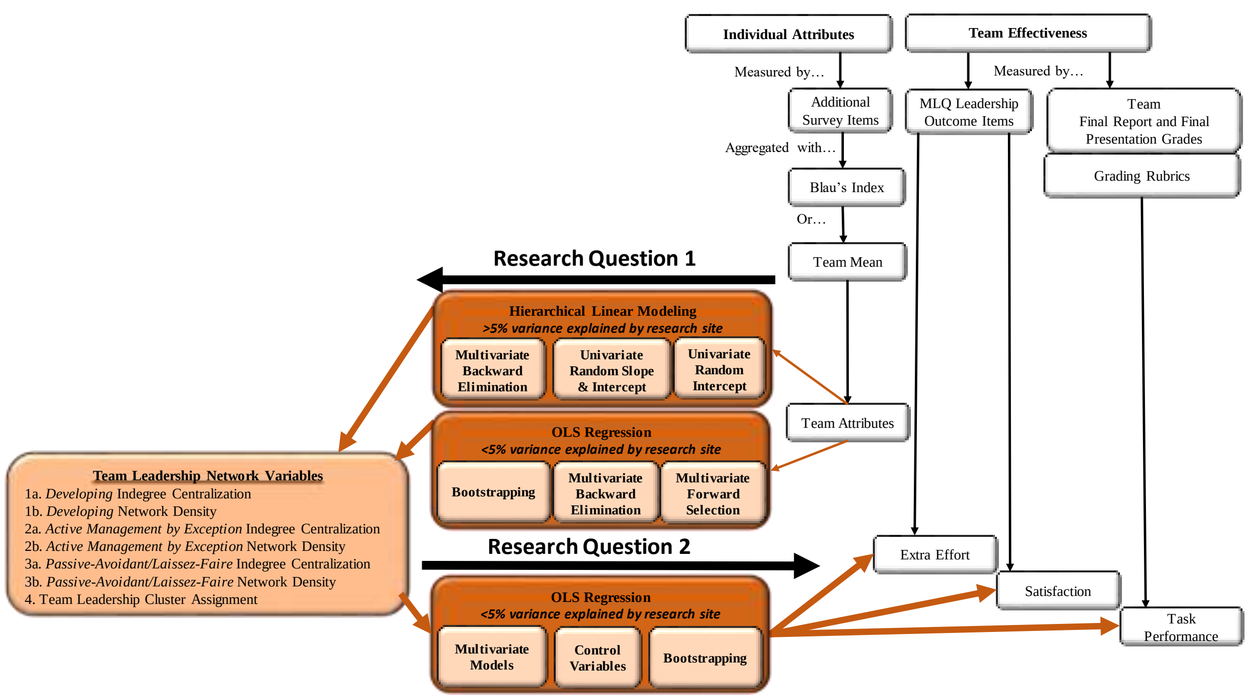


Figure 5.2: Methods Overview Flow Chart

5.4.2.2 Operationalizing Shared Leadership

Two measures of shared leadership are commonly calculated using social network analyses: 1) **network centralization** (i.e., variability of individual indices) and 2) **network density** (i.e., proportion of influence relationships within the team compared to the total number possible) (Gockel & Werth, 2010; Mayo et al., 2003). Gockel and Werth (2010) recommend subtracting network centralization values from one, resulting in a measure of **network decentralization** so that more positive values denote more shared leadership, and less positive values denote more vertical leadership. Graphical depictions of these shared leadership measures are shown in Figure 5.3. To date, researchers have focused on either decentralization or density independently (D'Innocenzo et al., 2014)—this research investigates both measures simultaneously, however, following the recommendation of Gockel and Werth (2010) and Mayo et al. (2003). Using both measures differentiates the very different leadership distributions that may result from full decentralization of leadership as depicted in the maximum decentralization graphic in Figure 5.3. Mayo et al. (2003) assert that teams with both high decentralization and density in their leadership networks exhibit shared leadership.

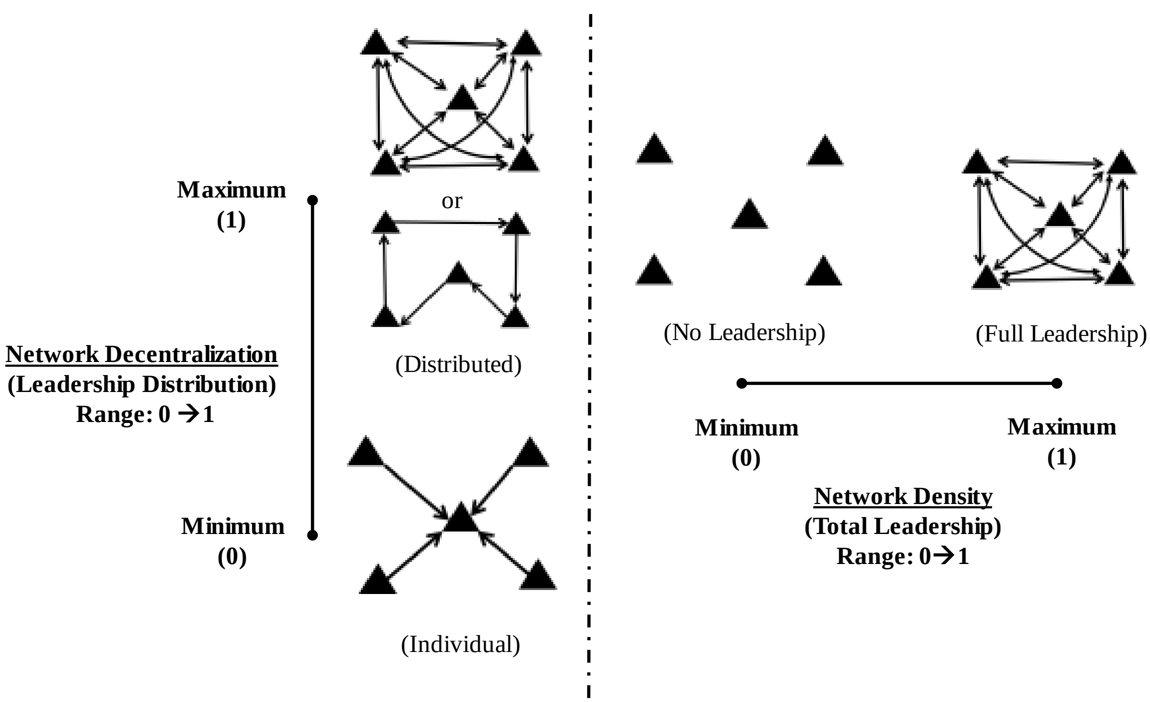


Figure 5.3: Shared Leadership Measure Examples.

Network analyses were completed using the SNA package in R. The team member ratings across the three separate scales were analyzed to determine the network decentralization and network density for each of the three forms of leadership, resulting in a total of six shared leadership measures: ***TCR decentralization, TCR density, MEA decentralization, MEA density, PA decentralization***, and ***PA density*** (see Table 5.4).

Table 5.4: Shared Leadership (Independent) Variable Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
						Statistic	Std. Error	Statistic	Std. Error
TCR Decentralization	45	0.25	1.00	0.68	0.19	-0.49	0.35	-0.51	0.69
TCR Density	45	0.25	0.80	0.63	0.14	-0.69	0.35	-0.16	0.69
Interaction TCR Decentralization-Density	45	0.09	0.80	0.44	0.18	-0.17	0.35	-0.67	0.69
MEA Decentralization	45	0.22	0.94	0.73	0.17	-1.02	0.35	0.67	0.69
MEA Density	45	0.05	0.67	0.35	0.14	0.07	0.35	-0.64	0.69
Interaction MEA Decentralization-Density	45	0.04	0.49	0.25	0.11	0.17	0.35	-0.67	0.69
PA Decentralization	45	0.25	1.00	0.84	0.19	-1.26	0.35	1.31	0.69
PA Density	45	0.00	0.36	0.05	0.07	2.30	0.35	7.42	0.69
Interaction PA Decentralization-Density	45	0.00	0.23	0.03	0.04	2.37	0.35	8.10	0.69

5.4.2.3 Operationalizing Team Effectiveness

We operationalized team effectiveness using a combination of measures. Team effectiveness is often categorized as a team's success in the accomplishment of assigned tasks in addition to a positive collaborative experience that leaves team members satisfied with the experience (Borrego, Karlin, et al., 2013; Hackman, 1990; Wageman, 2001). Wageman (2001) cites Hackman (1990) in her definition of three components of team effectiveness which are summarized in Table 5.5.

Table 5.5: Team Effectiveness Components from (Wageman, 2001)

Effectiveness Component	Definition
Group Process	The degree to which members interact in ways that allow the team to work increasingly well together over time.
Individual Satisfaction	The degree to which the group experience, on balance, is more satisfying than frustrating to team members.
Task Performance	The degree to which the team's product or service meets the needs of those that use it.

This combination of team effectiveness measures has parallels to common outcomes assessment of capstone design teams. Capstone faculty members often discuss *product* (i.e., successfully completing a large scale project) and *process* (i.e., learning various teaming skills) as competing tasks in their discussion of undergraduate engineering design teams (Paretti, Layton, Laguette, & Speegle, 2011). These components are similar to the *solution development* (product) and *learner development* (process) constructs articulated by Gerlick et al. (2008) for assessment outcomes of capstone design courses. Table 5.6 provides descriptive statistics for the team effectiveness measures (dependent variables) which will be further discussed in the following sections.

Table 5.6: Team Effectiveness Measure Descriptive Statistics

Team Effectiveness Component	Measure	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
							Statistic	Std. Error	Statistic	Std. Error
Group Process	Extra Effort Scale	45	2.18	5.00	3.86	0.67	-0.22	0.35	-0.44	0.69
Individual Satisfaction	Satisfaction Scale	45	2.63	5.00	4.09	0.56	-0.43	0.35	-0.15	0.69
Task Performance	Final Presentation Grade	45	85.00	99.00	92.51	3.86	-0.29	0.35	-0.88	0.69
	Final Report Grade	45	60.00	100.00	88.96	7.23	-1.82	0.35	5.41	0.69

5.4.2.3.1 GROUP PROCESS

The group process component of team effectiveness was operationalized as the team's ability to garner extra effort from its members. Blumenfeld et al. (1991) and Jones et al. (2013) highlight the challenges involved with maintaining student motivation and thoughtfulness over the duration of a prolonged project based learning experience. Finding ways to help teams garner extra effort from their members may be one way of alleviating this burden from faculty, and leadership may be one way to help foster that effort. In an early exploration of shared leadership, Avolio et al. (1996) found extra effort to relate positively to transformational and transactional leadership and negatively to passive-avoidant leadership for student teams in non-engineering contexts. Consistent with their methods, ***extra effort*** ratings were measured using a three-item scale variable that is included as a leadership outcome in the MLQ form 5X. The three items of this scale required team members to rate the frequency by which the rated member helped the rater to exceed their expected level of work and willingness to succeed using a five-point Likert-type scale: 1: Not at all; 2: Once in a while; 3: Sometimes; 4: Fairly often; 5: Frequently if not always. The mean of the three component items comprises the *extra effort* scale (α=0.90). Team member scale scores for all other team members and the faculty advisor were then averaged to create a team-level *extra effort* score. This score measured the frequency with which the team elicited extra effort from its team members. Because of copyright agreements, the actual items of this scale cannot be published.

5.4.2.3.2 INDIVIDUAL SATISFACTION

The individual satisfaction component of team effectiveness was operationalized as the team's overall satisfaction with the leadership and teamwork of its members. Satisfaction with the learning environment has been shown to strongly correlate with students' effort and achievement. At the university level, Pace (1983) found that, "students who were the most satisfied with college put the most into it and got the most out of it." (Pace, 1983, p. 33). Studies have also shown that students' satisfaction with collaborative learning experiences positively affect subjective measures of their learning (e.g., Lo, 2010). Examining student satisfaction with the teaming experience can provide indications as to whether that teaming experience is conducive to a positive learning environment.

Avolio et al. (1996) also found team member satisfaction to relate positively to levels of transformational and transactional leadership and negatively relate to passive-avoidant leadership for student teams in non-engineering contexts. Consistent with their methods, team member ***satisfaction*** ratings in this research were measured using a two-item scale variable (α=0.87) that is part of the MLQ form 5X. The two items of this scale required team members to rate the frequency by which the rated member worked with and led the rater in satisfactory ways using a five-point Likert-type scale: 1: Not at all; 2: Once in a while; 3: Sometimes; 4: Fairly often; 5: Frequently if not always. Team member scale scores for all other team members and the faculty advisor were averaged to create a team-level *satisfaction* score. This score measured the frequency by which the team members were satisfied with the leadership and teamwork enacted by its members. As with the previous measures, actual items cannot be published because of copyright reasons.

5.4.2.3.3 TASK PERFORMANCE

The task performance component of team effectiveness was operationalized as the team's performance on their final design presentation and design report as measured by course grades. The use of final project grades as a measure of task performance is consistent with Zafft et al. (2009), who used final design project grades to measure team performance in their study of leadership in student design teams. Including final design presentation grades as a second measure of task performance follows Brackin and Gibson (2002), who assert the inadequacy of the design report to evaluate both teaming skills and technical skills. The design presentation was specifically chosen as a second measure because of the incorporation of industry professionals into the evaluation process at all three research sites, which provides a different perspective on the team's performance.

A number of steps were taken to verify that using team grades as a measure of course performance across the three institutions was appropriate. Because the teams were nested in separate institutions with a separate grading rubrics, there was a concern that the teams' grades were measuring different things and would not be comparable across the three research sites. To mitigate this potential, we used a combination of rubric theme comparison and grade transformation to z scores, consistent with Stump, Husman, and Corby (2014), to ensure comparability of the grades. Appendix E provides a detailed comparison of the course requirements and associated grading rubrics for the presentation and report assignments as well as z score transformation.

5.4.2.3.4 CONTROL VARIABLES

To account for potential relationships that may provide alternate explanations of team effectiveness, we controlled for ***team size, team engineering GPA, team engineering GPA diversity, team sex***, and ***team leadership skills***. Although not an exhaustive list of alternate potential explanations of team effectiveness, the sample size of design teams included in the data set limited the number of variables that could be included in regression analyses. We specifically considered these variables because of the statistically significant relationships between these variables with measures of shared leadership for capstone design teams, which will be described in the team level variables section of this manuscript.

5.4.2.4 Relating Shared Leadership to Team Effectiveness (Research Question 1)

We used ordinary least squares (OLS) regression to address RQ1. Consistent with the recommendations of Keith (2006), we investigated the main effects and interaction effects of the density and decentralization measures across the TCR, MEA, and PA networks for each team effectiveness dependent variable. Models with statistically significant main or interaction effects were then aggregated into more complex models. The parsimonious models were then evaluated with the inclusion of control variables to determine if the relationships held while controlling for other potential explanations of team effectiveness.

We also used a follow-up bootstrapping analysis to evaluate the statistical significance of the relationships determined through OLS analysis. Bootstrapping is a resampling technique applied for data sets with small sample sizes that creates random sets from the original data using sampling with replacement (Field et al., 2012; Keith, 2006). To evaluate the robustness of the relationships, we conducted a 10,000-dataset bootstrapping analysis of the best-fitting OLS regression model for each of the four team effectiveness measures. These analyses provided both a regression coefficient *bias* (i.e., difference in the regression coefficient determined with the original data set and the mean of those determined with the bootstrapping samples) and the statistical significance of the regression coefficient across the 10,000 datasets. Evaluating these parameters added to our confidence that the identified relationship would hold for a larger population of capstone design teams.

To evaluate model fit, we took into consideration the variance explained by the models adjusted for the degrees of freedom (adjusted R^2), Akaike's Information Criterion (AIC) (Akaike, 1974), and the Bayesian Information Criterion (BIC) (Schwarz, 1978). Including these multiple criteria allowed for better assessment of the complexity of the regression models (Field et al., 2012; Miller, 2002). The variance explained by the regression model tends to increase as additional variables are considered (Field et al., 2012) thus favoring more complex models. However, both AIC and BIC penalize models with higher complexity, with BIC being a more conservative criterion (i.e., it corrects more harshly for additional model parameters) (Field et al., 2012). For both AIC and BIC, smaller values indicate a better model fit (Field et al., 2012; Miller, 2002). Incorporating all these criteria allowed for assessment of the most parsimonious model.

5.4.2.5 Team Level Variables (Independent Variables for Research Question 2)

Table 5.7 shows the descriptive statistics for each team level independent variable considered in the study; each variable is described subsequently

Table 5.7: Independent Variable Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
							Statistic	Std. Error	Statistic	Std. Error
Team Eng. GPA	45	2.00	4.00	6.00	4.92	0.52	0.40	0.35	-0.43	0.69
Eng. GPA Diversity	45	0.75	0.00	0.75	0.48	0.20	-1.38	0.35	1.29	0.69
Team Size	45	8.00	2.00	10.00	4.64	1.58	1.02	0.35	1.45	0.69
Team Leadership Skills	45	1.86	2.92	4.78	3.86	0.44	0.01	0.35	-0.48	0.69
Team Max Leadership	45	1.67	3.33	5.00	4.52	0.45	-0.51	0.35	-0.66	0.69
Team Sex	45	0.50	0.00	0.50	0.10	0.15	1.34	0.35	0.54	0.69
Race Diversity	45	0.67	0.00	0.67	0.30	0.22	-0.36	0.35	-1.20	0.69
Team Effort	45	1.47	3.40	4.87	4.23	0.37	-0.20	0.35	-0.75	0.69
Eng. Discipline Diversity	45	0.63	0.00	0.63	0.09	0.18	1.68	0.35	1.45	0.69
Team Tenure	45	3.00	1.00	4.00	2.20	0.82	0.52	0.35	-0.68	0.69

To characterize teams based on continuous (e.g., self-reported leadership skills) or dichotomous (e.g., sex) attributes, the team average score on the associated scale variable or individual survey item was used. For variables that included multiple categories (e.g., engineering discipline), indices of diversity were used to measure differences within teams. Previous studies have used Blau's Index for Diversity (Blau, 1977) to provide characterization of teams based on team member categorical differences. Small and Rentsch (2010), for example, used Blau's index for control variables in their social network study of student business teams. Because Blau's index has been successfully used in previous student team social network leadership studies, Blau's index was used for this study to allow for comparison of findings. Blau (1977) specifies the calculation of his diversity index as:

$$B = 1 - \sum_{i=1}^{k} p_i^2 \qquad [5.1]$$

In Equation 5.1, p_i is the proportion of group members in the ith category, and k is the total number of categories for the attribute of interest. This variable measures heterogeneity regarding grouping categories ranging from zero to one; teams with a Blau's index of zero would be homogeneous in one particular category (e.g., an all-Hispanic team), and teams with a Blau's index of one would show equal representation across all group categories.

Measurement of a student's engineering GPA took the form of student self-reported grades in their engineering specific courses. Previous studies have indicated that self-reported GPA provides a reasonable proxy for students' engineering discipline performance (e.g., Schlemer & Waldorf, 2010; Watson, 1998). A categorical item on the survey gathered this information, as follows: 1.49 or below (Below C-), 1.50-1.99 (C- to C), 2.00-2.49 (C to B-), 2.50-2.99 (B- to B), 3.00-3.49 (B to A-), and 3.50-4.00 (A- to A). The ***team engineering GPA*** variable is the team-wide average of student responses and provides an overall level of engineering course performance for the team. The ***engineering GPA diversity*** variable determined the heterogeneity of engineering GPAs across the team.

Team size refers to the number of students assigned to each design team. This variable was determined based on the student team rosters established in the course at the beginning of the Fall semester and was verified through a tally of survey responses. For large teams greater than ten students, students were asked to identify any sub-team structures that were being used by the team.

We used a 6-item leadership skills scale to measure students' self-reported leadership skills (Table 5.8). These items comprise a scale that was drawn from the National Science Foundation funded project entitled the Prototype to Production: Conditions and Processes for Educating the Engineer of 2020 (EEC-0550608) (P2P) that sought to benchmark undergraduate engineering vis-à-vis its progress toward developing the National Academy of Engineering's vision for the engineers of 2020 (see Lattuca, Terenzini, & Volkwein, 2006). For the current sample, the mean of these six items comprised a single scale variable (α=0.89) at the individual level. The mean team member scores characterized the average level of leadership skills within the team (***team leadership skills***). The individual scale score that was the maximum among the team members was a separate variable (***team max leadership***).

Table 5.8: Items comprising the Leadership Skills scale (α=0.89).

Rate your ability to:[1]
Identify team members' strengths/weaknesses and distribute tasks and workload accordingly.
Monitor the design process to ensure goals are being met.
Help your group or organization work through periods when ideas are too many or too few.
Develop a plan to accomplish a group or organization's goals.
Take responsibility for group's or organization's performance.
Motivate people to do the work that needs to be done.

[1]Likert scale: 1: Weak/none; 2: Fair; 3: Good; 4: Very good; 5: Excellent

Students' self-identified sex was recorded as a dichotomous variable at the student-level. A ***team sex*** variable accounted for the proportion of men and women on each team (mean of zero would denote all men, and a mean of one would denote all women).

To account for racial and ethnic differences among team members, items determining the ethnicity and race of each member were included in the survey (Table 5.9). Students with multiple responses to this question were classified in two ways. Consistent with current U.S. Department of Education policies (U.S. Department of Education, 2008), if students identified themselves as Hispanic in addition to other races, the student was classified as Hispanic. All non-Hispanic, multi-racial students were classified in a separate multi-racial category. Teams were classified by race/ethnicity using a ***team race diversity*** variable.

Table 5.9: Student Ethnicity/Race Survey Items

Question	Response Options
Are you Hispanic or Latino?	Hispanic/Latino Not Hispanic/Latino
What is your race? Choose one or more regardless of ethnicity.	American Indian or Alaskan Native Asian Black or African American Native Hawaiian/Other Pacific Islander White

To measure students' self-reported perceptions of project effort, we used an adaptation of the 5-item work effort scale employed by (Godard, 2001) in their study of the Canadian workforce. Table 5.10 provides a summary of the original version and modified items that were used in this study to quantify team member project effort. The original survey items formed a scale (α=0.78) measuring the degree to which individuals report effort in the performance of their work. For this study, the mean scores of the five adapted questions, which measure effort in their performance on the design project, comprised a single scale variable with high internal consistency (α=0.92). The team-level mean measured ***team effort***.

Table 5.10: Team member effort questions adapted from (Godard, 2001).

Original Question	Adapted Question[1]
You always put as much effort as possible into your work.	I always put as much effort as possible into my work on this design project.
You are highly committed to do the best job you can.	I am highly committed to do the best job I can on this design project.
For you, a good day at work is one in which you have performed to your utmost.	To me, a good work day is one in which I have performed to my utmost.
You try to work as hard as you can.	I try to work as hard as I can on this design project.
You intentionally expend a great deal of effort in doing your job.	I intentionally expend a great deal of effort on my academic work.

[1]Likert Scale: 1: Strongly Disagree; 2: Disagree; 3: Neither Agree nor Disagree; 4: Agree; 5: Strongly Agree

To account for engineering disciplinary differences among team members, an item determining the engineering major of each member was included in the survey. Responses to this question were aggregated into larger groupings of similar engineering major (e.g., EE/CS) and an expanded *Other* category that included students there were not included in the ME, GEN, or EE/CS categories). Teams were characterized using an ***engineering discipline diversity*** variable.

An item regarding prior work experience among team members and with the faculty advisor collected information about team tenure. Each team member was asked: "Rate the extent to which you have worked with each team mate prior to this teaming experience," with the following options: 1: Not at all; 2: Once in a while; 3: Sometimes; 4: Fairly often; 5: Frequently if not always. The ***team tenure*** variable accounted for the average amount of time students had worked together prior to the current design team experience using the mean response across all dyadic ratings.

5.4.2.6 Research Question 2 Analyses

To relate the degree of shared leadership within the teams to team level attributes for addressing research question two, we used a combination of ordinary least squares (OLS) regression and Hierarchical Linear Modeling (HLM). Because the 45 teams analyzed in this study were nested within three separate sites (A, B, and C), there was a potential to violate the case independence assumption of regression. If a significant level of variance can be explained by the site in which the team is nested, the cases cannot be considered independent (Field et al., 2012; Paterson & Goldstein, 1991; Raudenbush & Bryk, 2002; Snijders & Bosker, 2012). For example, teams may have had different levels of leadership training across sites that would affect the relationship between shared leadership and team level attributes. HLM allows the intercept and slope of the level 1 (i.e., team) model to vary by level 2 groupings (i.e., site) (see Raudenbush and Bryk (2002) or Snijders and Bosker (2012) for a full description of the method). As subsequently described, the level of variance explained by level 2 groupings (site) warranted HLM for TCR decentralization and TCR density.

Analysis proceeded by first considering only univariate, fixed effects models with random intercepts for each independent variable. Those models with significant fixed effects were then further analyzed using random effects models (i.e., varying slope and intercept). Finally, those variables with significant relationships were combined using backward elimination to elucidate the significant relationships while controlling for the effects of the other variables.

For all hierarchical linear modeling analyses, the independent variables were centered on the grand mean because the study focused on the relationships between team level attributes and shared leadership measures (Field et al., 2012). Grand mean centering was used because model results are consistent with those that are obtained using raw variable scores, and the models are more readily interpretable, especially when random slope models are considered (Field et al., 2012). A consequence of this centering is that the intercepts for these models do not correspond with a team exhibiting zero values of the independent variables, but rather an average value across those variables (Dedrick et al., 2009; Field et al., 2012).

To evaluate model fit, the variance explained by the models, adjusted for the degrees of freedom (adjusted R^2), Akaike's Information Criterion (AIC) (Akaike, 1974), and the Bayesian Information Criterion (BIC) (Schwarz, 1978) were all taken into consideration. Including these multiple criteria allowed for better assessment of the complexity of the regression models evaluated (Field et al., 2012; Miller, 2002). These analyses used the level 1 variance explained value (pseudo R^2) by Raudenbush and Bryk (2002) because the multiple random effects incorporated into HLM models make conventional R^2 calculations inappropriate (Luo & Azen, 2013). The variance explained by the regression model tends to increase as additional variables are considered (Field et al., 2012), thus favoring more complex models. As previously noted, however, both AIC and BIC penalize models with more complexity; smaller values indicate a better model fit (Field et al., 2012; Miller, 2002). Incorporating all these criteria allowed for assessment of a parsimonious model (i.e., least complex) that explained the most variance in the dependent variable.

To analyze the MEA and PA decentralization and density, HLM was not required because a negligible amount of variance was explained by research site differences. Instead, we used OLS regression to examine the relationships between team level attributes and MEA decentralization, MEA density, PA decentralization, and PA density. We performed a combination of stepwise regression and backward elimination of all independent variables to determine the most parsimonious model. In stepwise regression, the independent variables are sequentially added to the model if they are below a threshold criterion to enter the model; once added, are retained in the model only if they remain below a deletion criterion (Howell, 2013; Miller, 2002). Backward elimination works in the opposite direction from stepwise regression; all variables are entered into the model and then sequentially removed. Removal proceeds sequentially based on the smallest partial correlation with the dependent variable until no variables meet the removal criterion (Howell, 2013; Miller, 2002). For these analyses, the test criteria were set at $p=0.05$ to enter and $p=0.10$ to remove. Using both selection methods to explore appropriate models was informed by Miller (2002), who explains the limitations of each method when performed separately, and Broersen (1986), who proposes a method that uses backward elimination on a completed stepwise regression model to determine the parsimonious model. Unlike Broersen's (1986) process, however, because stepwise regression did not identify any statistically significant relationships for PA density or decentralization from which to begin building more complex models, backward elimination was performed using all independent variables to identify any significant relationships (Howell, 2013). Tests were performed using the STEPWISE and BACKWARD procedures in SPSS v23.[8] Similar to the HLM models, the multiple OLS models were evaluated using a combination of model variance explained (adjusted R^2), AIC, and BIC to determine the parsimonious model for the given dependent variable. We also used a follow-up bootstrapping procedure to evaluate the statistical significance of the relationships determined through OLS analysis.

5.4.3 Limitations

Several limitations should be acknowledged when interpreting the results. First, the 45 team sample represents a relatively small sample size with which to investigate relationships among the independent and dependent variables (Miller, 2002). This limited sample can be attributed to the challenges inherent to collecting full-team network data from students (Grunspan et al., 2014). Ideally, the significant relationships determined through exploratory analysis in this paper should be tested on another set of data (Miller, 2002); however, all cases were required to conduct the exploratory analysis. The study uses bootstrapping to strengthen the robustness of regression findings to help mitigate the low sample size. Despite this limitation, this relatively small number of teams still exceeds the sample size of other benchmark studies of shared leadership for engineering design teams; Zafft et al. (2009), for example, analyzed only seven teams in their quantitative study.

Second, this study focuses mainly in the mechanical engineering discipline and with senior-level engineering students at only three research sites. As a result, generality claims to the wider field of engineering across multiple disciplines, class years, institutions and to professional practice contexts are unwarranted.

Third, this study administered a reduced format of the MLQ survey. Although a full examination of all 36 MLQ leadership descriptive statements was desired, low student response rates in pilot data collection efforts prompted a decrease in survey length to help bolster survey

[8] For clarity, only the backward elimination results are shown as analysis proceeded with all variables under consideration; the stepwise results are discussed as appropriate.

response rates, as discussed in Novoselich and Knight (2015). It is therefore inappropriate to compare the specific findings of this study to those of other studies that incorporated all 36 MLQ leadership descriptive statements without acknowledging differences in data collection. Novoselich and Knight (Chapter 3) acknowledge these concerns in their validation study.

Fourth, there are limitations inherent to the use of survey data. Survey responses require recollection of events which is subject to memory distortion over prolonged periods (Singleton & Straits, 2010). As raters of other team members' leadership behaviors, students may feel threatened by the survey process (Zafft et al., 2009). Although confidentiality of the survey data was ensured and explicitly stated in the recruiting and informed consent processes, students may not have fully trusted the process (Hurley, 1998), especially since the names of all team members were included on the team-specific surveys to ensure rating accuracy. Consequently, student ratings may have been inflated to be more socially acceptable (Singleton & Straits, 2010).

Finally, the study did not require faculty advisors to reciprocally rate team members' leadership. This decision was made to maximize full-team responses; interactions with various course coordinators and faculty advisors indicated the potential for low faculty member response rates. Full team responses were required to generate team level ratings of each team member and for follow-on social network analysis to measure leadership sharing. The exclusion of the advisor's rating of the team members is inconsistent with the norms of social network analyses, creating potential gaps in the leadership networks. This facet of the study design does, however, reflect the reality that students may not possess the expert or legitimate social power with which to influence their faculty advisors through leadership actions.

5.5 Results and Discussion

5.5.1 Addressing Research Question 1: Relating Shared Leadership to Team Effectiveness

To determine the appropriate analysis method for relating measures of shared leadership to team effectiveness, the level of variance explained by level 2 (research site) groupings was examined. We examined the intra-class correlations of satisfaction and extra effort scale variables for the 45 teams (level 1) across the three research sites (level 2) (Table 5.11). The intra-class correlation is determined from a one-way random effects ANOVA, which determines the amount of variance between level two groupings (τ) and the amount of variance within level two (σ^2). The intra-class coefficient (ρ) is the ratio of level two variance to the total variance ($\tau+\sigma^2$) (Snijders & Bosker, 2012). Intra-class correlations were calculated using the MIXED procedure in SPSS v23 as explained by Peugh and Enders (2005). Because of the small number of level 2 groupings, we used the residual maximum likelihood method (REML) following the recommendations of Snijders and Bosker (2012) for models with less than 50 level 2 groupings. We did not examine the final presentation and final report z scores as the site level variation in these two variables was mitigated by conversion to z scores.

Table 5.11: Intra-class Correlations of Satisfaction and Extra Effort Scales.

	Level 1 n	Level 2 n	τ	Wald Z	p	$σ^2$	ρ
Satisfaction Scale	45	3	0.00	N/A	N/A	0.31	N/A
Extra Effort Scale	45	3	0.00	0.01	0.99	0.45	0.00

Intra-class correlations indicated that both of these two team effectiveness measures showed little level 2 between-group variance (Table 5.12). Results for the satisfaction scale, indicated that the co-variance parameter identified (site) was redundant, leading to no variance explained by level two groupings (τ). Because the research site explained no variance in the team effectiveness measures, ordinary least square (OLS) regression was appropriate (Field et al., 2012; Paterson & Goldstein, 1991; Raudenbush & Bryk, 2002).

5.5.1.1 Group Process Results

Evaluating the regression models for the *extra effort* measure of group process showed that the interaction of *TCR density* and *TCR decentralization* had the strongest relationship with *extra effort*. The statistically significant change in adjusted R^2 between models 1 and 2 showed that the interaction effects of *TCR decentralization* and *TCR density* were significant and should be retained in the model, as explained by Keith (2006). The parsimonious model (model 2) minimized BIC while explaining a similar level of variance in *extra effort* as model 9. The parsimonious model included both the main and interaction effects of both *TCR decentralization* and *TCR density* (Table 5.12). The interaction between *TCR decentralization* and *TCR density* maintained a negative relationship with *extra effort* across the breadth of models. This relationship held while controlling for shared MEA leadership, *team size*, *team eng. GPA*, *eng. GPA diversity*, *team leadership skills*, and *team sex* (models 7 and 9). Follow-on bootstrapping analysis also showed that the interaction remained statistically significant across the 10,000 unique datasets of 45 teams.

Shared MEA leadership interaction effects also showed statistically significant relationships when evaluated individually. The statistically significant change in adjusted R^2 between models 3 and 4 demonstrated the significance of the interaction between MEA decentralization and MEA density. The MEA interaction had a negative relationship with *extra effort*. When accounting for shared TCR leadership (model 7), however, these relationships were no longer significant. Shared PA leadership exhibited no significant relationships with *extra effort* (models 5 and 6). Among the control variables, only *team leadership skills* showed a significant relationship with *extra effort*.

Table 5.12: Extra Effort Scale Regression Model Summary

	Extra Effort Scale†									Bootstrap
N=45	**Model 1**	**Model 2+**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Bias/Sig.††**
Constant	**3.86*****	**3.95*****	**3.86*****	**3.81*****	**3.86*****	**3.84*****	**3.92*****	**3.86*****	**3.91*****	**-0.00 (p=.00)**
Team Size								-0.06	-0.14	
Team Eng. GPA								0.23	0.11	
Eng. GPA Diversity								-0.23	-0.02	
Team Leadership Skills								**0.43****	0.17	
Team Sex								-0.19	0.02	
MEA Decentralization			**0.29***	**0.39****			0.11		0.10	
MEA Density			**0.38***	**0.33***			0.05		0.06	
INT MEA Decen Dens				**-0.37***			-0.15		-0.12	
TCR Decentralization	**-0.27***	**-0.40*****					**-0.35****		**-0.26***	**0.01 (p=.00)**
TCR Density	**0.92*****	**0.94*****					**0.87*****		**0.72*****	**0.04 (p=.00)**
INT TCR Decen Dens		**-0.27****					**-0.23***		**-0.18***	**-0.29 (p=.01)**
PA Decentralization					0.18	0.19				
PA Density					-0.27	-0.29				
INT PA Decen Dens						-0.04				
Model Adjusted R^2	0.66	**0.72****	0.14	**0.25****	0.14	0.12	0.72	0.44	0.78	
AIC	-81.57	-88.65	-39.93	-45.13	-39.79	-37.85	-86.51	-56.28	-93.70	
BIC	-76.15	-81.42	-34.51	-37.90	-34.37	-30.62	-73.87	-45.44	-72.02	

†All independent variables are grand mean centered. (Standardized Coefficients)
††Bias and significance of coefficient based on 10,000 sample bootstrap analysis.
+Parsimonious Model
*=p≤0.05; **=p≤0.01; ***=p≤0.001

These analyses show that shared TCR leadership relates to the team effectiveness group process measure of *extra effort*. Examining the bootstrapping results, the statistically significant interaction effect between TCR density and TCR decentralization shows the moderating effect that TCR decentralization has on TCR density (Figure 5.5). Teams with low TCR decentralization show a stronger relationship between the density of TCR leadership within the team and *extra effort*. As the level of TCR decentralization increases, however, that relationship tends to get weaker. From this perspective, the amount of TCR leadership enacted by the team matters and positively relates to team members' engagement in the project, but this relationship is strongest for more vertical than shared leadership teams.

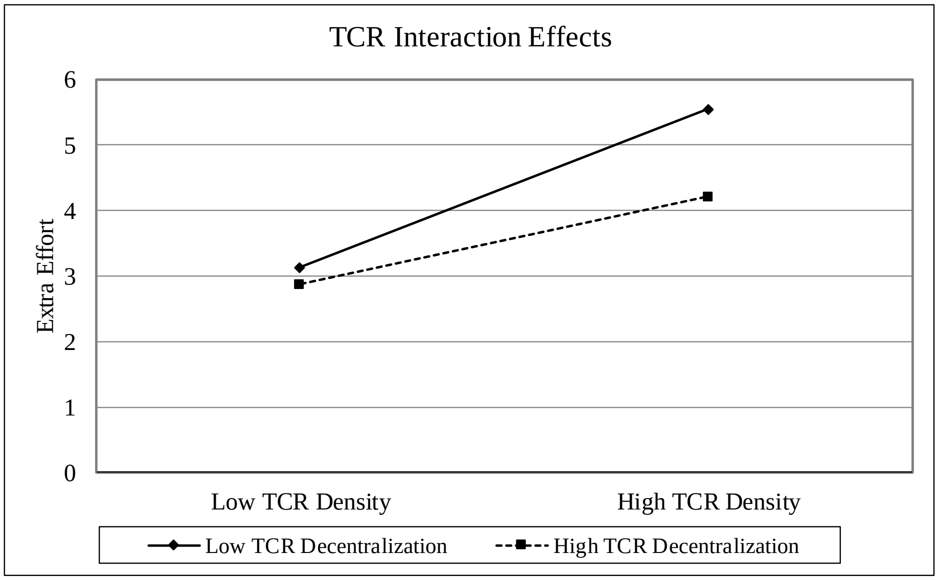


Figure 5.4: Interaction Effects of TCR Leadership Relationship with *Extra Effort*.

5.5.1.2 Individual Satisfaction Results

Examining regression models for the *satisfaction* scale showed that TCR and PA leadership significantly related to *satisfaction* (Table 5.13). Evaluating each form of leadership separately, *TCR density* exhibited a significant, positive relationship, but the relationship for *TCR decentralization* was negative (models 1 and 2). *MEA decentralization* and *MEA density* both showed significant, positive relationships with *satisfaction* (models 3 and 4). Only *PA density* showed a significant negative relationship with *satisfaction*. The non-statistically significant changes in adjusted R^2 between models 1-2, 3-4, and 5-6 suggested that the interaction effects of each form of shared leadership were not significant (Keith, 2006) and were not included in more complex models. The parsimonious model (model 7) minimized AIC and also maximized the level of variance explained by the model. Model 7 accounted for the main effects for all three forms of leadership and showed that only *TCR decentralization* and *TCR density* remained significant. Model 8 showed that among the team attribute control variables, *team leadership skills* had the only statistically significant relationship with *satisfaction*. Model 9 showed that when accounting for the various team attribute control variables, *TCR density* remained statistically significant. Finally, bootstrapping analysis of model 7 showed that across the 10,000 unique datasets of 45 teams, *TCR decentralization*, *TCR density*, and *PA density* all had significant relationships.

Table 5.13: Leadership Satisfaction Scale Regression Model Summary

	Satisfaction Scale[1]									Bootstrap
N=45	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Bias/Sig.[2]**
Constant	**4.09*** **	**4.11*** **	**4.09*** **	**4.06*** **	**4.09*** **	**4.06*** **	**4.09*** **	**4.09*** **	**4.09*** **	**-0.00 (p=.00)**
Team Size								0.03	-0.13	
Team Eng. GPA								0.24	0.11	
Eng. GPA Diversity								-0.17	0.06	
Team Leadership								**0.48*** **	0.16	
Team Sex								-0.19	-0.04	
MEA Decentralization			**0.42** **	**0.48*** **			0.12		0.12	-0.00 (p=.11)
MEA Density			**0.39** **	**0.35* **			0.01		-0.00	0.018 (p=.92)
INT MEA Decen Dens				-0.24						
TCR Decentralization	-0.17	**-0.21* **					**-0.24** **		-0.17	**-0.01 (p=.01)**
TCR Density	**0.94*** **	**0.95*** **					**0.86*** **		**0.75*** **	**-0.06 (p=.00)**
INT TCR Decen Dens		-0.07								
PA Decentralization					0.05	0.07	-0.03		0.03	-0.00 (p=.82)
PA Density					**-0.45* **	**-0.48* **	-0.24		-0.14	**-0.27 (p=.04)**
INT PA Decen Dens						-0.07				
Model Adjusted R^2	0.74	0.74	0.21	0.25	0.20	0.184	0.78	0.39	0.81	
AIC	-110.68	-109.37	-60.19	-61.46	-59.42	-57.553	-114.01	-68.68	-116.89	
BIC	-105.26	-102.14	-54.77	-54.23	-54.00	-50.32	-101.36	-57.84	-95.21	

†All independent variables are grand mean centered. (Standardized Coefficients)
††Bias and significance of coefficient based on 10,000 sample bootstrap analysis.
+Parsimonious Model
*=p≤0.05; **=p≤0.01; ***=p≤0.001

The *satisfaction* results again indicate that shared leadership relates to team effectiveness. Examining the final bootstrapping results, the positive coefficient for *TCR density* and negative coefficient for *PA density* show that team members are more satisfied with the team when more team members are engaged in influencing the team toward accomplishing its goals. Although *TCR density* had a stronger relationship than *PA density*, the statistical significance of *PA density* shows that team members are less satisfied with the experience when greater social loafing occurs within the team's leadership structure; students like being a part of engaged teams. These results are mathematically consistent with Avolio et al.'s (1996) results.

5.5.1.3 Task Performance Results

Regression model results for both final report grade and final presentation grade z scores exhibited no significant relationships between shared leadership and measures of task performance. Table 5.14 shows that only *team eng. GPA* had a statistically significant, positive relationship with *final report grade* (model 8). In Table 5.15, no statistically significant relationships were identified for *final presentation grade*. [9]

[9] For these analyses, only 44 teams were included in the data set. As sub-teams of a larger capstone design project, two of the 45 teams contributed to the same final design report and presentation. As a result, these two

Table 5.14: Final Report Grade Regression Model Summary

	Final Report Grade†								
N=44	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8⁺	Model 9
Constant	-0.01	0.06	-0.02	-0.08	-0.02	-0.11	-0.02	-0.02	-0.02
Team Size								-0.09	-0.14
Team Eng. GPA								**0.37***	0.29
Eng. GPA Diversity								0.29	0.39
Team Leadership Skills								0.07	-0.06
Team Sex								0.21	0.32
MEA Decentralization			0.12	0.19			0.05		0.06
MEA Density			-0.02	-0.06			-0.14		0.02
INT MEA Decen Dens				-0.28					
TCR Decentralization	-0.11	-0.19					-0.15		-0.17
TCR Density	0.31	0.32					0.36		0.40
INT TCR Decen Dens		-0.15							
PA Decentralization					-0.22	-0.19			
PA Density					-0.18	-0.25			
INT PA Decen Dens						-0.14			
Model Adjusted R^2	0.03	0.03	-0.03	**0.01***	-0.03	-0.04	0.01	0.08	0.08
AIC	-0.21	0.99	2.65	1.53	2.36	3.93	2.73	0.39	3.30
BIC	5.15	8.12	8.00	8.67	7.71	11.07	11.65	11.10	21.14

†All independent variables are grand mean centered. (Standardized Coefficients)
⁺Parsimonious Model
*=p≤0.05

The lack of significant relationships may be attributed to the variables used. This study capitalized on existing course-specific task performance evaluation methods rather than developing additional data collection measures of students' competencies or skills. Although an initial goal of the study was to partition technical evaluation of the final report and presentation from the non-technical evaluation to provide a more refined measure of task performance, this goal was not achieved. The subjective nature of team report grading at site A and an inability to recover completed grading rubrics for all teams across all three research sites prevented further refinement of task performance measured beyond the course-assigned numerical grade for the final report and presentation. A more refined measure of task performance with greater variability may provide additional insight into how shared leadership may relate to various aspects of capstone design tasks, such as solution innovation, overall team learning, or ability to meet customer needs.

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cases violated to case independence assumption of regression analysis. To maximize the amount of data available for analysis, one of these two teams were deleted case-wise.

Table 5.15: Final Presentation Grade Regression Model Summary

	Final Presentation Grade[†]								
N=44	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8[+]**	**Model 9**
Constant	0.02	0.04	0.01	-0.01	0.02	0.06	0.02	0.01	0.01
Team Size								0.18	0.21
Team Eng. GPA								0.33	0.28
Eng. GPA Diversity								-0.03	0.04
Team Leadership Skills								-0.12	-0.16
Team Sex								0.13	0.17
MEA Decentralization			0.06	0.09			-0.08		-0.18
MEA Density			-0.10	-0.12			-0.24		-0.12
INT MEA Decen Dens				-0.10					
TCR Decentralization	-0.00	-0.02					-0.01		-0.05
TCR Density	0.27	0.27					0.37		0.37
INT TCR Decen Dens		-0.04							
PA Decentralization					-0.06	-0.07			
PA Density					-0.17	-0.13			
INT PA Decen Dens						0.07			
Model Adjusted R^2	0.03	0.000	-0.03	-0.05	-0.03	-0.06	0.03	0.05	0.05
P		0.76		0.56		0.76			
AIC	0.34	2.30	2.77	4.40	2.81	4.70	2.11	1.55	5.10
BIC	5.70	9.43	8.12	11.53	8.16	11.84	11.03	12.25	22.95

[†]All independent variables are grand mean centered. (Standardized Coefficients)
[+]Parsimonious Model
*=p≤0.05

5.5.1.4 Research Question 1 Discussion (Hypothesis 1)

Results partially support *hypothesis 1*, which anticipated a positive relationship between shared leadership and team effectiveness (Table 5.16). Vertical leadership, when distributed across a limited number of team members, positively relates to team effectiveness measures of group process (*extra effort*) and individual satisfaction (*satisfaction*) but not task performance (course grades). These findings are consistent with Wang et al. (2014) whose meta-analytic study found weaker relationships between shared leadership and task performance than the attitudinal and behavioral process aspects of team effectiveness. Across the group process and individual satisfaction measures of team effectiveness, the amount (density) of leadership demonstrated positive relationships, indicating 'more is better' with regards to leadership. The way in which the leadership is distributed across the team matters as well. As leadership is more distributed across team members (i.e., decentralization), *extra effort* and *satisfaction* tend to decrease. The descriptive statistics of the shared leadership network measures shown in Table 5.4 however, show that no teams were characterized with decentralization scores of zero; thus, "vertical leadership" should not be synonymous with "individual leadership" for design teams. Leadership still emanates from multiple, albeit a limited number of, team members.

Correspondingly, these results suggest there may be an optimal model that is characterized by vertical leadership being distributed across a limited number of team members as a scenario that garners greater team effectiveness in terms of *extra effort* and *satisfaction*. Because of problematic measurements, we advocate for additional investigation of task performance before adequate claims can be made regarding this facet of team effectiveness.

Table 5.16: Summary of Research Question 1 Results

Research Question 1						
	Hypothesized Relationship Direction			**Results***		
	TCR	MEA	PA	TCR	MEA	PA
Group Process (Extra Effort)						
Hypothesis 1A: *The degree of shared TCR and MEA leadership will positively relate to team effectiveness.*	+	+		Partial (Int.)	Partial (Int.)	
Hypothesis 1B: *The degree of shared PA leadership will negatively relate to team effectiveness.*			-			
Individual Satisfaction						
Hypothesis 1A: *The degree of shared TCR and MEA leadership will positively relate to team effectiveness.*	+	+		Partial (Dens.)	Fully Supported	
Hypothesis 1B: *The degree of shared PA leadership will negatively relate to team effectiveness.*			-			Partial (Dens)
Task Performance (Course Grades)						
Hypothesis 1A: *The degree of shared TCR and MEA leadership will positively relate to team effectiveness.*	+	+				
Hypothesis 1B: *The degree of shared PA leadership will negatively relate to team effectiveness.*			-			

* **Partial**= hypothesis supported by one of two measures; **Dens.=** Density; **Decen.=** Decentralization; **Int.**=Interaction; gray=unsupported.

Hypothesis 1A and 1B were also partially supported. For hypothesis 1A, the amount (i.e., density) of TCR leadership showed robust, positive relationships, moderated by distribution (i.e., decentralization), for *extra effort*. The moderating effect of decentralization on density relationships for *extra effort* may indicate that an optimal leadership formula for garnering extra effort from a team may combine aspects of both vertical and shared leadership. In his article addressing the role shared leadership plays in creative, complex, and interdependent knowledge work, Pearce (2004) acknowledges the role of a central leader in developing an enabling structure for the team and communicating a uniting vision from which shared leadership may develop. In their description of vertical leadership, however, Mayo et al. (2003) acknowledge that influence may emanate from a select few central leaders within a team rather than a single leader. Further study of how leadership is distributed across the design teams may provide additional information to better understand if there is an optimal number of central leaders that may be more effective. Although this individual evaluation of leadership centrality is beyond the scope of the current study, the round-robin (360-degree) nature of the data collected for this study facilitates this deeper examination and is an area of on-going research for the authors.

For *satisfaction*, there was a robust, positive relationship with the amount of TCR leadership (i.e., density), but a negative relationship with TCR leadership distribution (i.e., decentralization). The negative relationship between *TCR decentralization* and *satisfaction* shows that as TCR leadership becomes more distributed across the teams, however, *satisfaction* tends to decrease. This negative relationship may provide indications that students become less satisfied with the teaming experience when influence comes from multiple team members; that finding coincides with the *extra effort* results discussed previously. Pearce (2004) articulates the importance of shared vision for the success of shared leadership. Within student teams, if the teams do not share a common vision, the distribution of leadership across team members may be problematic and less satisfying. This finding is an area worthy of further investigation.

Although preliminary regression models suggest shared MEA leadership may also positively relate to *extra effort* and *satisfaction*, these relationships did not remain significant while controlling for other variables. This result is also consistent with Wang et al. (2014) who found stronger relationships between shared 'new-genre leadership' (such as TCR leadership behaviors) compared to more traditional forms of leadership (which may include MEA). The lack of significant relationships in more complex models does not mean MEA leadership should be ignored. Engineering is a profession grounded in fundamental laws and professional standards for which engineers must remain accountable with their technical work. Correspondingly, MEA leadership is a necessary part of how engineers lead as demonstrated by the fact that it was present in all teams analyzed.

For hypothesis 1B, the amount of PA leadership negatively related with *satisfaction* and exhibited no significant relationship with either *extra effort* or course grades. Considering PA leadership as a form of social loafing, these results are not surprising. Social loafing is a recurring issue in team-based engineering student projects (Borrego, Karlin, et al., 2013) and work load distribution is a common source of student engineering team conflict (Paretti et al., 2013). Students seem to be more satisfied with the teams' leaders are responsive to the needs of the team.

5.5.2 Addressing Research Question 2: Team Level Attribute Relationships

To determine the appropriate analysis method for relating team level attributes to shared leadership measures, the level of variance explained by level 2 (i.e., research site) groupings was examined with intra-class correlations (Table 5.17). Intra-class correlations indicated that two different regression methods were appropriate for the data. *TCR decentralization* and *TCR density* had 14% and 19%, respectively, of the variance explained by level 2 groupings (site); MEA and PA decentralization and density had 5% or less variance explained by level 2 groupings. Thus, *TCR decentralization* and *TCR density* measures were analyzed using HLM, as differences across research sites explained over 10% of the variance in the measures (Porter, 2005); the remaining four network measures were analyzed using ordinary least square regression (OLS).

Table 5.17 Dependent Variable Intra-class Correlations Regarding Site

	Level 1 n	**Level 2 n**	**τ**	**Wald Z**	**p**	**σ^2**	**ρ**
TCR Decentralization	45	3	0.008	0.800	0.424	0.032	0.192
TCR Density	45	3	0.003	0.674	0.501	0.017	0.145
MEA Decentralization	45	3	0.002	0.522	0.602	0.028	0.059
MEA Density	45	3	0.000	N/A	N/A	0.020	N/A
PA Decentralization	45	3	0.000	N/A	N/A	0.036	N/A
PA Density	45	3	0.000	N/A	N/A	0.005	N/A

Because of the small number of teams incorporated in the study, the number of independent variables had to be narrowed. For regression analysis, Tabachnick and Fidell (1989) recommend a minimum 5:1 ratio of cases to independent variables, although larger ratios are preferred. With only 45 cases for analyses, the ten independent variables considered for this study were too great. To decrease variables, we used multiple criteria. First, we used correlation analysis to determine which independent variables had relationships with the dependent variables (Table 5.18). Second, we conducted a 'quick and dirty' best subsets regression analysis using the automatic linear modeling (LINEAR) algorithm in SPSS (2014) to determine what subsets of variables may be related to the each of the dependent variables.

Table 5.18: Variable Correlation Analysis

	Decentralization			Density		
	TCR	**MEA**	**PA**	**TCR**	**MEA**	**PA**
Team Size	.260	**.346****	-.103	.012	-.080	.204
Eng. Discipline Diversity	.032	.092	.186	-.293	-.105	-.159
Eng. GPA Diversity	-.079	-.109	-.287	**-.369***	-.075	.271
Team Sex	.049	.072	.179	-.090	**-.341***	-.252
Team Eng. GPA	.126	**.308***	.087	**.360***	-.095	-.105
Team Leadership Skills	.125	.169	.221	**.433****	.265	**-.385****
Team Effort	-.016	.077	-.023	**.326***	-.005	-.025
Team Max. Leadership	.105	.188	.118	.276	.162	-.273
Race Diversity	-.100	-.151	.036	-.117	.035	-.189
Team Tenure	-.047	-.056	.122	-.168	.144	-.166

*=p<0.05; **=p<0.01

Six of the ten variables had a statistically significant correlation with at least one of the dependent variables at the α=0.05 level and were retained for further analysis. Although the *eng. discipline diversity* variable did not show a significant relationship with the dependent variables, this variable was also retained because it showed significant relationships with the dependent variables in preliminary regression analyses.

5.5.2.1 HLM Results (TCR Leadership)

Evaluation of univariate random intercept models identified only *eng. GPA diversity* as significantly relating to *TCR decentralization* (Table 5.19). For comparison purposes, the table also includes the level zero random intercept model (HLM Baseline). For these analyses, model 3 was deemed parsimonious, as it had the highest variance explained of all models, illuminated a statistically significant relationship between the independent and dependent variables, and had the lowest AIC and BIC values. Model 8 further explored the relationship between *eng. GPA diversity* and *TCR decentralization* using a random effects model (i.e., varying both the intercept and slope by site); that model, however, had a poorer fit, and the relationship was no longer significant. Thus, these results identified model 3 as the most parsimonious model; as students with more widely varying engineering course performance are grouped together in a design team, the TCR leadership network becomes more centralized.

Table 5.19: TCR Decentralization Level 1 Model Results

	TCR Decentralization[†]								
	HLM Baseline	**Model 1**	**Model 2**	**Model 3[+]**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
Random Intercept	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Random Slope	No	No	No	No	No	No	No	No	Yes
Intercept	0.68***	0.68***	0.67***	0.68***	0.67***	0.67***	0.68***	0.68***	0.67***
Team Size		0.00							
Discp. Diversity			0.08						
Eng. GPA Diversity				-0.29*					-0.26
Team Sex					0.15				
Team Eng. GPA						0.03			
Team Leadership Skills							0.04		
Team Effort								0.02	
AIC	-17.74	-16.41	-15.93	-19.62	-16.17	-18.05	-17.52	-15.87	-15.74
BIC	-12.32	-9.19	-8.70	-12.39	-8.95	-10.82	-10.29	-8.65	-4.90
DF	3	4	4	4	4	4	4	4	4
σ^2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.0281
Pseudo R^2		-0.01	0.01	0.12	0.01	0.07	0.05	0.01	0.12

[†]Note: all independent variables are grand mean centered. (Standardized Coefficients)
[+]Parsimonious Model
*=p≤0.05; **=p≤0.01; ***=p≤0.001

Evaluation of univariate random intercept models using HLM identified four independent variables with statistically significant relationships with *TCR Density* (Table 5.20, models 1-4): *team leadership skills*, *engineering GPA diversity*, *team engineering GPA*, and *team effort*. All four statistically significant independent variables were further examined using a random effects model (models 8-11), which allowed both the slope and the intercept vary across level two groupings) (Snijders & Bosker, 2012). Coefficients of the independent variables all remained statistically significant, and the variance explained by the model increased slightly. The added complexity of these models, however, increased both the AIC and BIC values compared to the fixed effects models, indicating poorer model fit.

The final set of HLM models (12-15) included all statistically significant independent variables; a backward elimination examined the effects when other independent variables were accounted for. In models 12 and 13, no variables showed statistically significant relationships with *TCR density*. In model 14, both *team leadership skills* and *engineering GPA diversity* showed significant relationships at the $\alpha=0.05$ level. These significant relationships were further explored in model 15 by allowing both slopes to vary. Model 14 was deemed the parsimonious model for *TCR density* as it showed the lowest BIC of any model and illuminated statistically significant relationships between the independent and dependent variables. These results show that both *team leadership skills* and *eng. GPA diversity* significantly relate to *TCR density*. The direction of the *eng. GPA diversity* relationships remained consistent with those found in the *TCR decentralization* results previously discussed. Thus, these results show that the density of a team's TCR leadership network is related to both their diversity of engineering course performance and leadership skills. As students with more widely varying engineering course performance are grouped together in a design team, less TCR leadership occurs while as students with greater leadership skills are grouped together, the amount of TCR leadership increases.

Table 5.20: TCR Density Level 1 Model Results

TCR Density†

	HLM Baseline	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14^{+}	Model 15
Random Intercept	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Random Slope	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	Yes††
Intercept	0.62***	0.62***	0.62***	0.62***	0.63***	0.62***	0.63***	0.62***	0.62***	0.62***	0.61***	0.62***	0.62***	0.62***	0.62***	0.62***
Team Leadership Skills		0.045**							0.04**				0.02	0.03	0.03*	0.03*
Eng. GPA Diversity			-0.23***							-0.22**			-0.13	-0.14	-0.18*	-0.17*
Team Eng. GPA				0.03**							0.03*		0.01	0.02		
Team Effort					0.05*							0.05*	0.01			
Team Size						0.00										
Discp. Diversity							-0.17									
Team Sex								-0.04								
AIC	-45.93	-53.88	-54.86	-53.30	-48.99	-44.60	-47.34	-44.02	-50.17	-51.06	-52.46	-45.03	-56.49	-58.28	-57.74	-47.82
BIC	-40.51	-46.65	-47.64	-46.07	-41.76	-37.37	-40.11	-36.79	-39.33	-40.22	-41.62	-34.19	-43.84	-47.44	-48.7	-29.76
DF	3	4	4	4	4	4	4	4	6	6	6	6	7	6	5	10
σ^2	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
Pseudo R^2		0.20	0.25	0.22	0.10	0.04	0.05	-0.01	0.21	0.25	0.29	0.10	0.37	0.37	0.33	0.33

†Note: all independent variables are grand mean centered. (Standardized Coefficients)

††Random Slope for Eng. GPA Diversity Only

+Parsimonious Model

*=p≤0.05; **=p≤0.01; ***=p≤0.001

5.5.2.2 OLS Regression with Bootstrapping Results (MEA and PA Leadership)

Both *team size* and *team engineering GPA* significantly, positively related to *MEA decentralization* (see Table 5.21). For these analyses, model 6 was deemed parsimonious. Although it explained slightly less variance in *MEA decentralization* than model 5, both AIC and BIC were minimized. Forward selection also identified this model at its stopping point, corroborating this model as being parsimonious. Thus, the distribution of MEA leadership is related to both how well team members perform in their engineering courses and the size of the team. As students with higher engineering course performance are grouped into larger teams, the distribution of MEA leadership tends to increase.

Table 5.21: MEA Decentralization Backward Elimination Regression Models.

	PA Decentralization†					
N=45	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6+**
Constant	**1.17***	**1.146***	**1.032***	**1.066***	**1.184****	**0.967*****
Eng. GPA Diversity	-.367	.210	-.344	-.312	**-0.358***	**-0.330***
Discpline Diversity	.183	.210	.201	-.196	.232	.244
Team Effort	-.150	-.137	-.160	-.148	-.093	
Team Leadership Skills	.165	.155	.148	0.131		
Team Size	.099	0.098	.083			
Team Eng. GPA	-.106	-.092				
Team Sex	.088					
Model Adjusted R^2	.020	.039	.057	.075	.086	.099
AIC	-143.663	-145.316	-147.017	-148.725	-150.163	-151.758
BIC	-129.210	-132.670	-136.177	-139.692	-142.936	-146.338

†Note: all independent variables are grand mean centered. (Standardized Coefficients)
+Parsimonious Model
*=p≤0.05; **=p≤0.01; ***=p≤0.001

Both *team leadership skills* and *team sex* significantly related to *MEA density* (Table 5.22). For these analyses, model 6 was deemed parsimonious, as it explained the greatest variance in *MEA density* and both AIC and BIC were minimized. Standardized coefficients show that *team sex* is slightly stronger and negatively relates to *MEA density* and *team leadership skills* positively relates to *MEA density*. These relationships remained consistent across the breadth regression models, even when considering the effects of the other independent variables. Forward selection also identified this model at its stopping point, corroborating this model as being parsimonious. Thus these results demonstrate that the amount of MEA leadership that occurs in a team relates to how well students perceive their leadership skills and the proportion of women in the team. As the proportion of women grouped on a team increases, less MEA leadership occurs, while as the average level of leadership skills increases, so does the amount of MEA leadership.

Table 5.22: MEA Density Backward Elimination Regression Models.

	MEA Density†					
N=45	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6+**
Constant	.288	.291	.209	.137	.104	-.023
Team Leadership Skills	**0.414***	**0.409***	**0.435***	**0.411***	**0.381***	**0.325***
Team Sex	**-0.340***	**-0.340***	**-0.328***	**-0.352***	**-0.379***	**-0.391****
Team Effort	-.130	-.128	-.133	-.161	-.122	
Discpline Diversity	-.097	-.099	-.118	-0.111		
Team Eng. GPA	-.140	-0.136	-.111			
Eng. GPA Diversity	-.083	-.073				
Team Size	.021					
Model Adjusted R^2	.113	.136	.155	.165	.174	.182
AIC	-174.143	-176.122	-177.925	-179.366	-180.746	-182.085
BIC	-159.690	-163.476	-167.085	-170.332	-173.519	-176.665

†Note: all independent variables are grand mean centered. (Standardized Coefficients)
+Parsimonious Model
*=p≤0.05; **=p≤0.01; ***=p≤0.001

Only *engineering GPA diversity* had a statistically significant, negative relationship with *PA decentralization* (Table 5.23); model 6 was the parsimonious model. Although the BIC value was slightly than for model 6, model 7 explained considerably less variance in the dependent variable. The relationship between *engineering GPA diversity* and *PA decentralization* was inconsistent across the breadth of models, showing a lack of statistical significance when considering the effects of multiple other variables. Forward selection analysis did not identify any significant relationships. The result indicate that as students with more widely varying performance in their engineering courses are grouped into design teams, PA leadership tends to centralize on fewer members of the team.

Both *team leadership skills* and *team effort* had statistically significant relationships with *PA density* (Table 5.24), with model 5 deemed the most parsimonious model. *Team leadership skills* relates slightly stronger and negatively to *PA density*, and *team effort* relates positively. The *team effort* relationship remained statistically significant across the breadth of regression models; *team leadership skills* only became significant when all other variables other than *team sex* were removed. The results show that the amount of PA leadership that occurs within the design teams relates to the leadership skills of the team members and the level of effort the team members put into the design project. As students with greater leadership skills are grouped into design teams, the amount of PA leadership decreases and as the team exerts greater effort on the project the amount of PA leadership tends to decrease.

Table 5.23: PA Decentralization Backward Elimination Regression Models.

	PA Decentralization†						
N=45	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6+	Model 7
Constant	**1.17***	**1.146***	**1.032***	**1.066***	**1.184****	**0.967*****	**0.972*****
Eng. GPA Diversity	-.367	.210	-.344	-.312	**-0.358***	**-0.330***	-.287
Discpline Diversity	.183	.210	.201	-.196	.232	.244	
Team Effort	-.150	-.137	-.160	-.148	-.093		
Team Leadership Skills	.165	.155	.148	0.131			
Team Size	.099	0.098	.083				
Team Eng. GPA	-.106	-.092					
Team Sex	.088						
Model Adjusted R^2	.020	.039	.057	.075	.086	.099	.061
AIC	-143.663	-145.316	-147.017	-148.725	-150.163	-151.758	-150.832
BIC	-129.210	-132.670	-136.177	-139.692	-142.936	-146.338	-147.219

†Note: all independent variables are grand mean centered. (Standardized Coefficients)
+Parsimonious Model
*=p≤0.05; **=p≤0.01; ***=p≤0.001

Table 5.24: PA Density Backward Elimination Regression Models.

	PA Density†				
N=44	Model 1	Model 2	Model 3	Model 4	Model 5+
Constant	-.016	-.016	-.015	-.053	.025
Team Sex	-.196	-.196	-.206	-.223	-.261
Team Leadership Skills	-.257	-.256	-.268	-.284	**-0.358***
Team Effort	**0.374***	**0.373***	**0.384***	**0.356***	**0.331***
Eng. GPA Diversity	.184	.183	.172	.212	
Team Eng. GPA	-.115	-.116	-.118		
Discipline Diversity	-.035	-0.03			
Team Size	-.003				
Model Adjusted R^2	.092	.116	.138	.151	.135
AIC	-256.654	-258.654	-260.600	-262.101	-262.166
BIC	-242.380	-246.164	-249.895	-253.180	-255.029

†Note: all independent variables are grand mean centered. (Standardized Coefficients)
+Parsimonious Model
*=p≤0.05; **=p≤0.01; ***=p≤0.001

5.5.2.3 Bootstrap Results

Bootstrap analysis of the parsimonious OLS models indicated that three of the four models remained significant with more robust team data. The regression coefficient bias (i.e., difference between original data coefficient and mean of the random sample coefficients) and two-tailed statistical significance of the regression coefficient resulting from bootstrap analysis are shown in Table 5.25. For all but *PA network density*, the reported p-values indicate that relationships remained significant across the 10,000 unique datasets of 45 teams at the α=0.05 level. These results add confidence in the robustness of three of the four model results. For *PA network density*, however, neither *team leadership skills* nor *team effort* remained significant across the 10,000 unique datasets of 45 teams, so results of the density model should be approached with caution.

Table 5.25: Regression Bootstrap Bias and Significance Results

Variable	Hypothesis	MEA Decentralization	MEA Network Density	PA Decentralization	PA Network Density
Constant		-0.13 (p=.995)	0.003 (p=.900)	**-0.004 (p=.000)**	-0.002 (p=.332)
Team Eng. GPA	Hypothesis 2	**0.001 (p=.011)**			
Eng. GPA Diversity	Hypothesis 3			**0.008 (p=.006)**	
Team Size	Hypothesis 4	**0.001 (p=.011)**			
Team Leadership Skills	Hypothesis 5		**-0.001 (p=.037)**		-0.003 (p=.79)
Team Sex	Hypothesis 7		**0.004 (p=.011)**		0.001 (p=.128)
Team Effort	Hypothesis 9				0.003 (p=.205)
Discipline Diversity	Hypothesis 10			-0.004 (p=.063)	

5.5.2.4 Team Attribute Relationship Discussion (Hypotheses 2-11)

These results failed to fully support any of hypotheses 2-11 because each independent variable only related to selected components of the dependent variables. A summary of the relationships found through the various analyses is shown in Table 5.26. Statistically significant relationships that were identified but did not hold for the parsimonious model and/or bootstrapping are described as inconclusive. Unsupported hypotheses are shown in gray.

Table 5.26: Summary of Research Question 2 Results.

Attribute	Hypothesis	Hypothesized Relationship Direction: TCR	MEA	PA	Results*: TCR	MEA	PA
Team Eng. GPA	***Hypothesis 2:*** *Team average self-reported engineering course GPA will have a positive relationship with shared TCR and MEA leadership and a corresponding negative relationship with shared PA leadership.*	+	+	-	**Inc. (Dens.)**	**Partial (Decen.)**	
Eng. GPA Diversity	***Hypothesis 3:*** *Teams self-reported engineering course GPA diversity will have a negative relationship with shared TCR, MEA, and PA leadership.*	-	-	-	**Supported**		**Partial (Decen.)**
Team Size	***Hypothesis 4:*** *Team size will have a negative relationship with shared TCR and MEA leadership and a positive relationship with shared PA leadership.*	-	-	+		**Opp. (Decen)**	
Team Leadership Skills	***Hypothesis 5:*** *The average level of leadership skills within the team will positively relate to shared TCR and MEA leadership and negatively relate to shared PA Leadership.*	+	+	-	**Partial (Dens.)**	**Partial (Dens.)**	**Inc. (Dens.)**
Max Leadership	***Hypothesis 6:*** *The maximum individual leadership score within a team will negatively relate to shared TCR and MEA leadership and positively relate to shared PA leadership.*	-	-	+			
Team Sex	***Hypothesis 7:*** *The proportion of women assigned to a design team will have positive relationships with shared TCR leadership and negative relationships with shared MEA and PA leadership.*	+	-	-		**Partial (Dens.)**	
Racial/ Ethnic Diversity	***Hypothesis 8:*** *Racial and ethnic diversity on a team will have a negative relationship with shared leadership development.*	-	-	-			
Team Effort	***Hypothesis 9:*** *Average team level effort will have a positive relationship with shared TCR and MEA leadership and a negative relationship with shared PA leadership.*	+	+	-	**Inc. (Dens.)**		**Inc. Opp. (Dens.)**
Eng. Discipline Diversity	***Hypothesis 10:*** *Team engineering discipline diversity will have a positive relationship with shared TCR and MEA leadership and a negative relationship shared PA leadership.*	+	+	-			
Team Tenure	***Hypothesis 11:*** *The amount of time team members have worked together prior to the current project will positively relate to shared TCR and MEA leadership and negatively relate to shared PA leadership.*	+	+	-			

***Supported**= hypothesis fully supported; **Partial**= hypothesis supported by one of two measures; **Opp.**= relationship opposite of hypothesis. **Inc.**= inconclusive results, some relation may exist; **Dens.**= Density; **Decen.**= Decentralization;

Engineering GPA was most related with shared leadership, as anticipated by hypotheses 2 and 3. Hypothesis 2 was inconclusive for TCR leadership, partially supported for MEA leadership, and not supported for PA leadership. TCR leadership showed only an inconclusive relationship with *team mean GPA* indicating that students' technical ability may relate to TCR leadership, but further inquiry is warranted. *Team mean GPA* related positively with shared MEA leadership, but only for the decentralization measure, thus partially supporting hypothesis 2. From this relationship, it appears as if students' technical ability relates to leadership within their capstone design experience. Teams with overall higher technical ability had more students engaged in the accountability behaviors of the MEA network. Students may be more willing to examine critically the work of others and hold them more accountable for performance within a project. The lack of corresponding relationship for *MEA density* indicates that the increased involvement of team members in the MEA network does not necessarily extend to all members of the team.

Hypothesis 3 was fully supported for TCR leadership, unsupported for MEA leadership, and partially supported for PA leadership. *Engineering GPA diversity* had negative relationships with both the decentralization and density of the TCR network as anticipated. As design teams become more diverse in student technical ability, TCR leadership becomes more centralized, and the number of leadership connections decreases. These results suggest that a select few students are enacting TCR leadership within the team when teams are diverse with respect to past academic performance. With GPA as a proxy for technical ability, these results may be a manifestation of the technical mastery leadership orientation identified by Rottmann et al. (2014). Through this leadership orientation, engineers who are confident in their own technical competence and are recognized by peers for this competence lead other team members through formal and informal technical mentoring relationships. Teams with a broader range of engineering GPAs represented may have fewer technical masters available for mentorship. The higher performing students may be serving in more centralized technical mastery roles because of their increased expert power (French & Raven, 1959; Northouse, 2013), and the less technically proficient may have less expert power with which to influence their peers. This dynamic would simultaneously decrease both the decentralization and density of the network. Because developing team member strengths is a facet of TCR leadership, the nature of these technical mentoring relationships may feel more transformational in nature than forcing accountability, thereby explaining why the relationship exists for TCR but not for MEA.

Partially supporting *hypothesis 3*, *engineering GPA diversity* showed a negative relationship with *PA decentralization* but not density. As the students on the low end of the engineering GPA spectrum fail to influence their peers in the TCR and MEA network, they may be identified as having more PA leadership behaviors. This small number of students would explain the negative relationship between *engineering GPA diversity* and *PA decentralization*. The corresponding centralization of PA leadership however, does not include a corresponding decrease in *PA density*. This lack of reduction in density may be a result of the overall low density of the PA networks. The *PA density* mean in Table 5.4 shows that on average, only 5% of the possible PA ties in a network actually occur within the teams and, at most, only 36% occur. The overall low density of PA leadership shows that these relationships are occurring mainly at the dyadic level (i.e., member to member), so there is only a small range for which the *PA density* may decrease.

Hypothesis 4 was not supported; shared leadership did not relate to team size in the directions anticipated. *Team size* only had a significant relationship with *MEA decentralization* but in the opposite direction hypothesized. Larger teams tended to distribute leadership rather than centralize, but only for the MEA network. This relationship shows that as teams are larger, the accountability actions inherent to MEA leadership are distributed among multiple students. This trend may result from an effort to mitigate the effects of social loafing. Social loafing is more likely to occur within larger teams (Karau & Williams, 1993). To prevent these actions from adversely affecting the team, more students may be bearing the burden of monitoring accountability. The lack of a corresponding density relationship may be explained by a lack of strong integration within larger teams. (Cox et al., 2003) summarize research suggesting team size having a marginally negative effect on work integration, which would account for the disparate MEA relationships observed. As the team gets larger, social loafing behaviors may only be observed more sporadically, increasing the variance in MEA density and preventing coherent trends. The lack of relationship between team size and the TCR and PA networks indicates that students engage in shared TCR and PA leadership to varying degrees across the range of team sizes. In general, there is a dearth of literature regarding relationships between shared leadership and team size with which to help interpret these results. Nicolaides et al. (2014) describe how team size is most often treated often as a “nuisance variable to be controlled for statistically” (p. 926) and D'Innocenzo et al. (2014) describes how this non-purposeful treatment of team size hinders further exploration in meta-analytic study. In proposing a positive relationship between team size and shared leadership, (Cox et al., 2003) acknowledge that potential ambiguous effects of team size. All three works advocate continued exploration of these relationships.

Hypothesis 5 was partially supported for TCR and MEA leadership and inconclusive for PA leadership. *Team leadership skills* had the anticipated relationships with both TCR and MEA density but not decentralization. As the teams' mean, self-reported engineering leadership skills increased, so did the number of leadership ties in both the TCR and MEA networks. There was also some evidence of a decrease in PA density, although this relationship did not hold up under stricter statistical scrutiny. These results are consistent with leadership self-efficacy trends discussed in the literature review. Consistent with Paglis (2010), when team members collectively perceived themselves as having more leadership skills they seem more willing to enact TCR and MEA leadership and are potentially less prone to absentee (PA) leadership behaviors. The lack of relationship between *team leadership skills* and leadership distribution may indicate that teams distribute the forms of leadership in different ways. These results suggest that a team with a high density of leadership does not necessarily mean that everyone is leading. The greater number of ties commensurate with increased leadership density may be distributed across multiple team members in some teams yet attributed to a more select few in other teams. According to distributed leadership theories, the roles team members take on, (e.g., mentor, instructor, coach, or facilitator) relates to how leadership is distributed within the teams (Burke, Fiore, & Salas, 2003), especially in early stages of team development. Examining the relationships between a team member’s prominence within the leadership networks and their individual leadership skills would help uncover these differences but is beyond the scope of this work. Further exploration of the teams at the individual level may help interpret the lack of relationships in the decentralization of leadership. Small and Rentsch (2010) describe the scant empirical study of the distributed aspect of shared leadership. Further investigation may help fill this gap in the literature.

Hypothesis 6 was not supported. No statistically significant relationships were uncovered relating to a team's maximum leadership. The maximum measure did not account for the overall team mean leadership skills. The degree to which the maximum leader differed from the mean of the team (i.e., z score) may have been a more effective measure of maximum leadership skills and could be considered in future research designs. A team's maximum leadership could remain an area of further inquiry. From a social identity perspective of leader emergence, the first phase of a leader's emergence is their appearance of exerting influence over others within a group (Jackson & Parry, 2011) and according to leadership self-efficacy, a person may be more apt to demonstrate leadership (influence) over others is they are more self-confident in their leadership abilities. This research stream may help unpack the emergence of leaders within the teams.

Hypothesis 7 was unsupported for TCR leadership, partially supported for MEA leadership, and unsupported for PA leadership. *Team sex* had a significant negative relationship with *MEA density*, partially supporting Hypothesis 7. This relationship indicates that as the proportion of women on a team increased, the number of ties within the MEA network tended to decrease. These results may be related to gender differences in the way men and women lead, as described in the literature review. Women in other contexts outside of engineering, on average, tend to be more oriented on enhancing others' self-worth with their leadership style than men, exhibiting more TCR and less MEA or PA behaviors than their male counterparts (Eagly et al., 2003; Vinkenburg et al., 2011). This same trend may be present within the engineering design teams; as the proportion of women increase, the overall level of MEA may tend to decrease within the team. Perhaps the lack of relationships between the sex composition of the teams and either TCR or PA leadership may be attributed to the relatively small differences between women and men Eagly et al. (2003) found which may be compounded by the rearranging of the leadership factors by Novoselich and Knight (Chapter 3) that resulted in the TCR, MEA, and PA leadership scales investigated. Gender differences across the leadership scales in the capstone design context is an area worthy of further inquiry at both the individual and team level. The relatively low representation of women in this study may have contributed to the lack of significant findings.

Hypothesis 8 was unsupported. No discernable relationships were uncovered regarding race and ethnicity within the teams. This lack of relationship must also be viewed with the understanding that there were very few underrepresented minority students within the study sample. Racial and ethnic relationships to team leadership skills are complex issues, as discussed in the literature review and should be an area of further inquiry within contexts that allow for in-depth analysis.

Hypothesis 9 was unsupported across all three forms of leadership; there were inconclusive relationships in the TCR and PA networks. *Team effort* showed positive, but inconclusive, relationships with *TCR density*. The potential positive relationship between team member effort and TCR leadership is not surprising considering the amount of effort this form of leadership may require. Implementing a TCR leadership system may require strong physical effort to overcome organizational (or group) obstacles (Avolio, 2011). The inconclusive, positive relationship between *team effort* and *PA density* is a little more problematic. This relationship indicates that as the overall level of project effort increases within a design team, so does the number of ties in the PA network. There a two potential explanations for this. First, if students are working harder on a project, they may be more self-consumed in their personal contributions to the project and less willing or able to engage other students within the team (i.e., the divide and conquer approach to teamwork), which their peers may perceive as PA behavior. Another potential explanation may be that an increase in PA behaviors by a select few social loafers within the team may result in increased effort by the rest of the team to compensate for the social loafers' lack of leadership and direction. Social loafing is cited as the most prominent problem in team-based engineering student projects (see Borrego, Karlin, et al., 2013). Future work could specifically examine how social loafing relates to leadership within design teams.

Hypothesis 10 was unsupported. No statistically significant relationships were uncovered between a team's *engineering discipline diversity* and shared leadership. It is possible that the disciplinary expertise non-ME students bring to an ME project may not be recognized by the ME students as a source of expert power from which to influence the team. The lack of relationship for engineering discipline diversity should be interpreted with caution, however, because of the overall low representation of non-ME majors in the teams. Future work could compare discipline-centric teams to interdisciplinary teams to see if there are any differences in team leadership processes.

Hypothesis 11 was unsupported, as no statistically significant relationships were uncovered relating to a team's tenure. The lack of significant relationships between shared leadership and students' prior work experiences with one another may be attributed to a low representation of teams with strong prior work experience within the data. These results may also indicate that the teams are afforded ample time within the capstone design course with which to build the relationships necessary for sharing leadership among the team members. These relationships should remain an area of further inquiry. Nicolaides et al. (2014) explain that although team tenure may promote shared leadership, the effectiveness of shared leadership may decay with time. Their study found that team tenure moderates the shared leadership-team performance relationship over a prolonged duration.

5.6 Conclusions

For engineering educators, three main conclusions emerge from this study of shared leadership within undergraduate student design teams.

1. **Leadership for undergraduate capstone design teams is a complex phenomenon, encompassing both distribution and amount across three different leadership forms.**

Across the three forms of leadership, this study identified different relationships between decentralization and density with both team effectiveness and team attributes. For engineering education and engineering leadership researchers, results show that both the amount and distribution of leadership, or the interaction between the two measures, are important considerations for undergraduate engineering student design teams. This study highlights the utility of measuring shared leadership using both network decentralization and density in a *rate the members* approach. Previous studies have used an aggregated *rate the team* approach or considered network density and network decentralization separately in measuring shared leadership. These previous studies have shown positive relationships between shared leadership and team effectiveness or team performance (D'Innocenzo et al., 2014; Wang et al., 2014). Our current study has investigated both density and decentralization to better render the complexity of effectively sharing leadership. This dynamic should be accounted for in future research designs, especially because our study demonstrates that specific forms of leadership do not consist of a singular set of behaviors. Thus, researchers should be purposeful in how they operationalize leadership within their studies.

2. **Regarding team effectiveness, although shared leadership may be more pervasive than vertical leadership within mechanical-engineering centric capstone design teams:**

    a. **Sharing leadership across the full breadth of a team may not be an effective strategy.**

The results show that a distributed, vertical form of leadership may be an optimal strategy for mechanical engineering centric capstone design teams. This classification of leadership, that maximizes the amount of leadership happening within the team while limiting the distribution of leadership to a select few team members, was most consistent with increased team effectiveness measures. As students and faculty structure design teams, this study provides evidence that teams could be encouraged to adopt an approach to leadership that increases the amount of leadership enacted while also accounting for and coping with divergent influence from team members to maintain a focus on team goals, consistent with previous research indicating the shared nature of leadership in undergraduate engineering teams (Feister et al., 2014; Zafft et al., 2009). An immediate strategy may be to limit leadership distribution within teams based on the results of this study. More importantly, faculty may need to help teams develop strategies to evaluate conflicting influences from within the team and stay focused towards their common goals, which is consistent with the assertions of Muethal and Hoegl (2013) and Schaeffner et al. (2015) regarding professional teams. As interventions are developed that help students understand and incorporate shared leadership into their teamwork processes, the moderating or negative effects of leadership distribution may diminish. The result may be more engaged teams as they exert extra effort and are more satisfied based on this study's results.

b. Encouraging one central leader within the team may create a leadership structure that is inconsistent with how leadership actually occurs within design teams

Although a more vertical leadership strategy may be more effective for student design teams, "vertical leadership" may not be synonymous with "individual leadership." Faculty that attempt to specify or encourage a single leader within the design team may unintentionally establish a leadership structure that is inconsistent with the collaborative nature of design work. The results of this study suggest that within design teams, more leadership within the teams may create more engaged teams as it relates positively to measures of extra effort and satisfaction. Identifying one central leader may artificially truncate the amount of leadership that could occur within the team. Although distributing leadership had a moderating or negative relationship with measures of team effectiveness, no teams in the study exhibited individual leadership, consistent with previous descriptions of the shared, fluid nature of undergraduate engineering team leadership (e.g., Feister et al., 2014; Zafft et al., 2009). Leadership structures encouraged through team charters of course specific guidance could acknowledge this reality of design team leadership

c. The type of leadership enacted by the team is important.

Engineering educators could also encourage students to enact leadership behaviors consistent with TCR leadership. The results indicate that leadership is not a spectator sport, as evidenced by the negative relationship between PA density and team member satisfaction which is indicative of PA leadership behaviors (Antonakis & House, 2013). Rather, TCR leadership, which is based on positive reinforcement and is the most active form within the Full Range of Leadership model, had the most robust relationships with team effectiveness measures, consistent with other meta-analyses (D'Innocenzo et al., 2014; Wang et al., 2014). TCR-type leaders develop their fellow team members' strengths, maintain a compelling vision, show a strong sense of purpose, and instill pride in team members while challenging methodologies (Novoselich & Knight, 2015). These leadership behaviors may create a more engaged team overall by shaping the way team members interact as Chi and Huang (2014) assert. Although the accountability associated with MEA leadership showed significant relationships when considered separately, consistent with previous transactional leadership findings (Antonakis & House, 2013; Lowe et al., 1996) and may be important for the technical, standards-based field of engineering, TCR leadership dominated the parsimonious models for team effectiveness among the leadership behaviors in more complex leadership models.

3. **Several team attributes relate to the level of shared leadership within design teams:**
    a. **Team Engineering GPA and Engineering GPA diversity**

The study indicates that the engineering discipline ability of students, as measured by engineering course GPA, has the strongest, most prevalent relationships with the degree of shared leadership across the three networks, consistent with expert power providing a source of influence (French & Raven, 1959; Pierro et al., 2013; Tonso, 2007). For engineering faculty wishing to develop effective leadership strategies within the teams as a part of the capstone experience, these results indicate that the GPA of the team members may play a role in determining the types of leadership experiences the team member will have. Assigning students to teams in a way that increases the mean GPA of the team may provide overall greater leadership engagement for those teams but may also result in overall low leadership engagement for low mean GPA teams. GPA disparity within the team, in contrast, may result in a lack of leadership experiences for some team members, as the higher performing students have the potential to serve in what Rottmann et al. (2014) call technical mastery roles. As shared leadership related to team effectiveness in this study, higher GPA teams may exhibit extra effort and satisfaction, leading to more engagement in the project. More diverse GPA teams may exhibit less extra effort and satisfaction and overall less engagement.

b. **Team Leadership Skills**

Preparing students for the leadership challenges of a capstone design experience may also be important in shaping the shared leadership of the design teams. Faculty may consider how they develop engineering leadership skills in their students prior to the capstone experience and the prior leadership experiences of the team members during team formation. The significant relationships between *team leadership skills* and network density across the three networks shows that how students perceive themselves as leaders plays a role in the amount of leadership enacted in the team, which in turn related to measures of team effectiveness and consistent with Paglis (2010) and Smith and Foti (1998). Providing students opportunities to exhibit leadership, assess performance, and reflect on their leadership skills (a type of on-the-job training) may provide them the leadership awareness necessary for them to be more active contributors to the leadership networks of their design team (Farr & Brazil, 2012). Although these self-perceptions did not relate to how leadership was distributed across the teams, it did contribute significantly to the amount of leadership happening within the teams, which in-turn relates positively with both the extra effort and satisfaction of the team.

c. Team Size and Team Sex

Team size and sex may also help shape shared leadership within undergraduate engineering student design teams. In general, the relationships were inconsistent with previous studies relating leadership and sex (Eagly et al., 2003; Vinkenburg et al., 2011) or social loafing (Karau & Williams, 1993). Neither variable related to TCR leadership, but both related to MEA leadership, which involves maintaining accountability of students within the team. As faculty assign students to teams within the capstone design course, these two variable may relate to how students hold each other accountable. While mentoring teams, faculty may need to pay closer attention to how accountability happens in larger teams since these results indicate it is more distributed in larger teams. For faculty with mixed sex teams, faculty may also want to monitor the team accountability procedures to ensure team leaders continue to hold team members accountable, as MEA density tended to decrease with an increased proportion of women on the team.

5.7 Future Work

Moving forward, this study has raised a series of questions that are worthy of further inquiry. First, the moderating or negative relationships between leadership distribution and team effectiveness highlights the need for a better understanding of effective leadership distribution strategies for design teams. Further inquiry at the individual team member level is ongoing with the current dataset but is beyond the scope of this study. Additional qualitative research may also provide insights into the complexity of this phenomenon beyond what the available numerical data provide. Second, along this same research stream, investigating additional sources of leadership within design teams is warranted. This study specifically considered only faculty advisors and student team members. As a result, other sources of influence or leadership, such as teaching assistants, customers/clients, and subject matter experts outside the team, were not investigated. Future studies may include these potential sources of influence to see how they are situated in the leadership networks. Third, the lack of significant relationships between shared leadership and course grade were contrary to previous research findings relating shared leadership and task performance in other contexts. Further inquiry is warranted to determine how leadership relates to engineering design team task performance using more purposefully developed measures than course assigned grades. Nevertheless, the exploratory nature of this study raises many new questions regarding leadership in design teams, all of which may help build and refine models for how engineers lead.

Chapter 6

Leadership for Capstone Design Teams

6.1 Introduction

The purpose of this study was to investigate leadership processes within undergraduate mechanical engineering-centric capstone design teams to 1) determine the applicability of the shared Full Range of Leadership model, and 2) determine the relationship between sharing the Full Range of Leadership and team effectiveness. To meet those objectives, the study addressed the following research questions:

> **RQ3.1:** To what extent do the scales that emerge from a modified Multifactor Leadership Questionnaire used to measure the Full Range of Leadership fit the undergraduate ME-centric student design team context?
>
> **RQ3.2:** To what degree do the emerging leadership scales demonstrate validity by relating to other variables in expected ways?
>
> **RQ4.1:** To what degree is leadership shared within undergraduate mechanical engineering-centric capstone design teams?
>
> **RQ4.2:** To what degree does the level of shared leadership classify undergraduate mechanical engineering-centric capstone design teams?
>
> **RQ5.1:** How does the degree of shared leadership across the Full Range of Leadership relate to undergraduate mechanical engineering-centric capstone design team effectiveness?
>
> **RQ5.2:** How do team-level attributes relate to the degree of shared leadership in undergraduate mechanical engineering-centric capstone design teams?

This chapter synthesizes the findings of Chapters 3-5 that address those research questions through a single illustration of effective leadership for mechanical engineering-centric capstone design teams. The chapter then discusses implications of those findings in terms of engineering education practice and engineering education research. The chapter concludes with a proposal of future work that will stem from this dissertation.

6.2 An Illustration of Effective Leadership for ME-Centric Capstone Design Teams

6.2.1 The Full Range of Leadership for Design Teams

Chapter 3 applied the Full Range of Leadership Model to the ME-centric capstone design team context. Addressing research question 3.1 in Chapter 3 established leadership constructs that emerged from the Full Range of Leadership model within the mechanical engineering-centric capstone design teams. A combination of prior published exploratory factor analysis using all 36 leadership descriptive statements of the Multifactor Leadership Questionnaire (MLQ) and follow-on confirmatory factor analysis of a 14-item subset of the MLQ established that ME-centric capstone design teams enact leadership in three forms:

> **Transformational/Contingent Reward (TCR) Leadership:** Developing team member strengths, maintaining a compelling vision, showing strong sense of purpose, and instilling pride in team members. This construct combines aspects of both the transformational leadership scale and the contingent reward factor of the original Full Range of Leadership model.
>
> **Active Management by Exception (MEA) Leadership:** Maintaining a consistent focus on standards; identifying and tracking mistakes among team members. This construct is directly interpretable with the management by exception (active) factor of the original Full Range of Leadership model.
>
> **Passive-Avoidant (PA) Leadership:** Either a delay in action until serious issues arise or a total absence of involvement, especially when needed. This construct combines the laissez-faire with the passive management by exception factor of the original Full Range of Leadership model.

The confirmatory factor analyses conducted in Chapter 3 established the internal structure evidence of validity for these leadership constructs. These three forms of leadership are exhibited simultaneously in varying degrees by the members and advisors of the ME-centric capstone design teams; they are not mutually exclusive. There was a strong, positive correlation between TCR and MEA leadership ratings. PA leadership also showed strong, negative correlation with TCR leadership and moderate, negative correlation with MEA leadership.

Analyses addressing research question 3.2 in Chapter 3 produced additional evidence for the validity of these three leadership constructs beyond the internal structure evidence. The three forms of leadership exhibited varying degrees of correlation with student self-reported leadership skills and, to a lesser degree, self-reported team member effort. The corresponding scale variables also distinguished students based on their self-reported engineering course GPA. These relationships between the leadership scales and other variables related to leadership provide evidence that the scales measure students' leadership behaviors.

6.2.2 Shared Leadership in Design Teams

Research question 4.1, addressed in Chapter 4, situated the three forms of leadership within a shared leadership framework. We used a combination of network decentralization and network density measures to operationalize shared leadership within the teams, following the recommendations of Mayo et al. (2003) and Gockel and Werth (2010). The findings related to research question 3 indicated that all three forms of leadership tend to be more shared than vertical across the 45 teams included in the sample.

Research question 4.2, also addressed in Chapter 4, specified a classification system for shared leadership in teams. Results indicated that the quadrant system of shared leadership classification first proposed by Mayo et al. (2003) was adequate for classifying shared leadership within ME-centric capstone design teams. Cluster analyses differentiate the teams into two distinct groups across each of the six measures of shared leadership incorporated into the study.

6.2.3 Shared Leadership's Relationship to Team Effectiveness and Attributes.

Chapter 5 related the shared leadership framework to measures of team effectiveness and describes relationships between team attributes and the level of shared leadership within design teams. An overarching finding from Chapter 5 that addresses research question 5.1 is that leadership related to team effectiveness for measures of *extra effort* and *satisfaction*, but not for course grades. Regression results indicated that density had positive relationships with team effectiveness for both TCR and MEA leadership and negative relationships for PA leadership. Decentralization exhibited a moderating effect on density for TCR and MEA leadership in relation to *extra effort*. Also, decentralization showed a negative main effect for TCR leadership and a positive main effect for MEA leadership related to *satisfaction*. These results indicated that there is a band of effective amounts of decentralization for TCR and MEA leadership, with somewhat greater MEA decentralization than TCR decentralization; leadership was optimal when shared among a few team members, not the whole team, but also when it did not rest with a single individual.

Regression models indicated that TCR leadership exhibited the strongest positive relationships with team effectiveness measures, and MEA leadership showed weaker relationships when considered separately. Analyses addressing research question 5.2 established relationships between team attributes and the degree to which forms of leadership are shared. *Team engineering GPA, engineering GPA diversity, team leadership skills, team sex*, and *team size* all related to either the decentralization or density (or both) of one or more forms of leadership. Other team attributes exhibited inconclusive or no relationships with the decentralization or density of the three forms of leadership.

6.2.4 Visualizing Effective Design Team Leadership

Addressing the six research questions of this dissertation produced a summary illustration of effective leadership for mechanical engineering-centric capstone design teams (Figure 6.1). Each of the three studies contained in Chapters 3-5 add layers of complexity to the illustration.

Chapter 3 established the 3 forms of leadership (i.e., TCR, MEA, and PA) enacted by the capstone design teams, which is a modification of the Full Range of Leadership model for the ME capstone context. As a result, Chapter 3 established the need for three separate forms of leadership (PA, MEA, and TCR) in Figure 6.1.

Chapter 4 determined the degree to which the three forms of leadership were shared among the teams and specified a classification strategy for team leadership. Thus, results in Chapter 4 correspondingly situated the three forms of leadership within the shared leadership framework of Figure 6.1. The framework accounts for both amount (density) and distribution (decentralization) to describe how a team shares each form of leadership.

Decentralization and density are the dimensions used to differentiate four different team classifications related to shared leadership, labeled as Shared Leadership, Low Shared Leadership, Vertical Leadership, and Leadership Avoidance. Relatively high and low decentralization and density scores differentiate the four classifications.

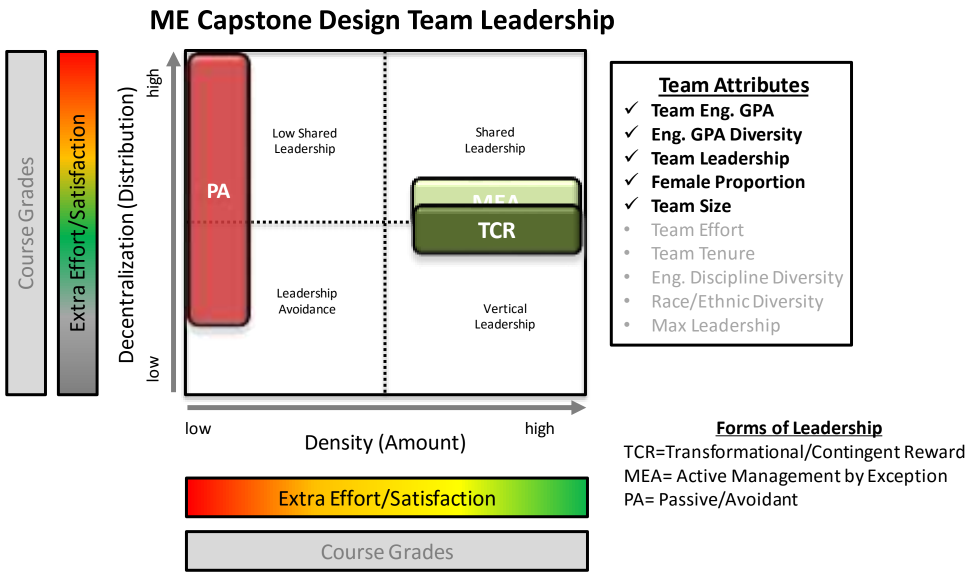

Figure 6.1: ME-Centric Capstone Design Team Leadership Graphic

Chapter 5 relates the three forms of leadership within the shared leadership framework to team effectiveness and team attributes. Accordingly, Chapter 5 adds team the Extra Effort/Satisfaction and Course Grades measures of team effectiveness to the graphic, adds shape and position of the three forms of leadership within the shared leadership framework, and identifies team attributes that are related to the degree of leadership sharedness within the teams. In Figure 6.1 the red to green coloring of the Extra Effort/Satisfaction bar on the density axis reflects the positive relationships leadership density had with measures of team effectiveness in the TCR and MEA regression models. Correspondingly, the regions of effective leadership (ovals) for TCR and MEA tend toward higher density for these two leadership forms, signify a desire for high TCR and MEA density in design teams. With respect to decentralization, the color scale of the Extra Effort/Satisfaction bar signifies the moderating or negative relationship TCR and MEA decentralization had with these two team effectiveness measures. The gray area of the bar signifies a region of decentralization that was not represented with the team data in this study. Both TCR and MEA Leadership are also centrally located on the decentralization axis and limited in height to signify that both forms of leadership are shared to some degree in teams (none of the 45 teams displayed individual leadership), but that decentralization could be limited. In Figure 6.1 The darker green coloring for TCR leadership in comparison to MEA leadership and the overshadow of TCR leadership signifies how when TCR and MEA leadership were combined in more complex regression models, TCR leadership remained significant while MEA did not. PA leadership tends toward lower density and is colored a translucent red to reflect a need to minimize this form of leadership for team effectiveness. PA leadership also covers the range of decentralization by which the team data reflected to signify that there is no relationship between PA decentralization and team effectiveness measures within the range covered in this study. In Figure 6.1, Course Grades remains gray to signify the lack of relationships with shared leadership determined by this study. Finally, the team attributes box shows checks for those team attributes that relate to shared leadership in this study and lists all attributes investigated to encourage future consideration of these variables.

This illustration provides a preliminary framework by which mechanical engineering capstone design students and faculty may better understand the leadership phenomenon. Investigating the phenomenon from a shared leadership perspective, this illustration conceptualizes leadership as a three-form influence process varying in both amount and distribution within engineering design teams. Because this research was informed by the Full Range of Leadership model, the breadth of leadership literature related to the constructs it contains may provide additional insight into effective leadership practices from which engineers may draw and provide much needed insight into how to develop these practices in student engineers.

Context is an important consideration for interpreting this study of shared leadership. Although much of the literature that informed this research related to professional contexts, including both engineering and other disciplines, the academic environment within which we conducted this research differentiates itself from professional practice in a number of ways (Stevens, Johri, & O'Connor, 2014). First, the novice and peer nature of the 45 teams incorporated into this study would be hard to replicate in professional practice. Stevens et al. (2014) describes professional engineering practice as heterogeneous; consequently, professional design teams would most likely be comprised of engineers with varying levels of professional experience and subject matter expertise. These differences may create a more vertical leadership environment than the more homogeneous student teams of this research. Second, task performance has different connotation in the professional environment when compared to the academic setting studied. The student teams may have much greater ability to fail in their design task than would a professional team. Because the capstone design course is still a learning environment, a satisfactory outcome of the experience may produce a failed design, but a lot of learning could still occur based on how and why the team failed in their design task (Paretti et al., 2011). In a professional engineering environment, similar outcomes would be an unrealistic long-term business model. Thus, the relationships between shared leadership and task performance may differ across contexts. In light of these distinctions, additional research is warranted before this model may be applied to professional engineering practice.

6.3 Implications

6.3.1 Implications for Engineering Education Practice

Identifying shared leadership as an appropriate model for undergraduate engineering design teams may inform how capstone design faculty discuss and promote leadership within their classes. Course tools, such as team charters, used to facilitate team formation may inadvertently push students toward team leadership approaches that are inconsistent with the realities of how leadership actually happens within the teams. For example, the specification of a single leader at two of the three sites in this study contradicts the pervasive shared leadership that actually occurred within the design teams and is an inconsistent approach with the ways in which shared leadership related to team effectiveness. These results suggest that a more appropriate means for addressing the formation of leadership may be to identify multiple leadership roles and responsibilities. Facilitating this level of discussion may help create an enabling team structure that can promote greater effectiveness by allowing multiple leaders to emerge within the team.

The shared leadership illustration developed in this study provides an additional resource that faculty may consider when mentoring design teams. By modeling effective leadership practices themselves and making students aware of effective leadership processes, faculty may allow a more satisfying capstone design experience and increase the engagement of the students. TCR leadership outweighed both MEA and PA leadership behaviors in its relationship to team effectiveness. Faculty may consider adopting TCR behaviors and encourage students to adopt them as a part of their capstone design team experiences. The results of this study provide indications that teams may put forth additional effort and be more satisfied with the experience, both of which may promote greater learning for students.

The results of this study provide additional evidence to support the importance of team composition for undergraduate capstone design teaming processes. For faculty wishing to address leadership skills as a part of the capstone design experience, how students are assigned to teams may play a role in students' leadership processes and experiences. Students' engineering course GPA showed the strongest relationships with shared leadership, with greater GPA diversity relating to decreased shared leadership. A more equitable distribution of GPAs across the team may increase leadership sharing within the teams. In addition, students' leadership self-efficacy could become a consideration for faculty, as results indicated that teams with higher self-reported leadership skills engaged in more, active leadership. Finally, the size and sex of the team may play a role in the level of MEA leadership that occurs. Understanding these leadership dynamics may provide capstone design faculty the ability to better tailor the capstone design experience to meet the developmental needs of students preparing for leadership roles in engineering professional practice.

6.3.2 Implications for Engineering Education Research

Identifying shared leadership as a pervasive model within capstone design teams may change how researchers conceptualize the phenomenon of leadership, particularly for the engineering context. The results of this study encourage the broadening of leadership conceptualizations beyond its historical embodiment within a single person, as multiple individuals play a role in leading design teams. Researchers considering the leadership of only one individual within design teams may artificially reduce the complexity of team leadership.

This study developed a new methodology for quantitative study of a team-level phenomenon for engineering design teams. Using a combination of social network analysis and more traditional statistical techniques, this study operationalized the theoretical propositions of Mayo et al. (2003), Gockel and Werth (2010), and Cox et al. (2003). Leader-follower relationships occurring across the breadth of the design team were distilled into both decentralization and density measures that could be used as both dependent and independent variables for follow-on analysis. Teamwork researchers may consider the use of social network analyses for various other teamwork related topics involving multiple interactions, such as social loafing, shared cognition, communication, or situated knowledge distribution.

By applying the Full Range of Leadership model to the undergraduate engineering design team context, this study opens a wealth of literature from which engineering education researchers may better understand leadership within engineering design teams. The three forms of leadership explored in this study were conceptually similar to forms identified by other leadership scholars outside the undergraduate engineering design team context. Consequently, the wide range of scholarly publication regarding the Full Range of Leadership model may help engineering education researchers develop ideas for understanding the leadership phenomenon for engineers; the engineering education community may not need to start from scratch.

Finally, the illustration developed in this study provides a framework and taxonomy of leadership behaviors that may help researchers classify engineering leadership behaviors and sharing. This study provides a common frame of reference and terminology for which future engineering education researchers can discuss leadership-related findings.

6.4 Future Studies

The results of this study encourage the following areas for further exploration:

- Comparison of leadership decentralization and density relationships to team effectiveness separately so that results may be more directly compared with previous quantitative studies.

- Replication of the current research design within other engineering disciplines, across multiple academic years, and for professional practice to determine variations of findings from those of this study.
- Investigation of student team member prominence in the leadership networks to determine characteristics of students who tend to exhibit different forms of leadership within design teams.
- Investigation of faculty advisor prominence in the leadership network to determine relationships with shared leadership and team effectiveness.
- Exploration of other sources of leadership for capstone design teams beyond those covered in this study (e.g., Graduate Teaching Assistants, Clients, Sponsors, or Subject Matter Experts).
- Qualitative study to better understand how leadership roles transition across individuals within the design teams.
- Structural equation modeling of shared leadership and team effectiveness, which allows for leadership decentralization and density to serve as both dependent and independent variables within a single model.

6.5 Concluding Remarks

An original intent of this study was to make leadership more approachable to engineers and engineering educators. Through over two years of work, I am unsure whether this study met that objective. What I have been able to show is that leadership is a complex influence process when examined at the team level. Complexity, however, can often be a result of a combination of many simpler things. A friend once told me that the Space Shuttle may seem complex, but it is really just a bunch of nuts and bolts. The complexity comes from how the nuts and bolts are stacked together. My hope is that this inaugural, team-level investigation of shared leadership does not detract from one central theme that I have personally experienced in my over twenty years of professional leadership experience. Leadership is about people—people as individuals. This study has illuminated three forms of leadership enacted by people when placed in a capstone design team context. The form of leadership that focuses most on caring for the individual person (TCR) has the strongest relationships with team effectiveness. It further highlights that leadership is most often a shared activity among multiple team members for capstone design teams, and sharing leadership in that way may increase the team's extra effort and satisfaction. I hope that readers can walk away from this dissertation with those two central themes; if so, then I consider this work a success.

In many ways, the completion of this dissertation is a new beginning. The study has illuminated a number of implications for engineering education practice and research. Results show that purposeful leadership development may provide an additional resource for faculty to enhance the capstone design experience and prepare students as future engineering leaders. That can only be the case if these results are shared with the broader community, and this dissertation was written in a three manuscript (Chapters 3-5) format for that reason. At the time of publication, the manuscripts contained in this document are either in preparation for or under review by engineering education scholars. My sincere hope is that those manuscripts may help engineers pause and reconsider how they conceptualize leadership and realize its utility as an influence process for reaching design team goals.

Appendix A: Summary of Pilot Exploratory Factor Analysis.

Exploratory factor analysis was conducted using the maximum likelihood method with oblique rotation using the Oblimin with Kaiser normalization rotation method (Novoselich & Knight, 2015), and six-, three-, and nine-factor models were considered based on eigenvalues. Novoselich and Knight (2015) ultimately determined that a three-scale model was most suitable for use because of its consistency with the Full Range of Leadership Model.

Substantive differences between the theory's original leadership constructs and those that emerged from data analysis required a re-naming of the three scales. Scale 1, which was comprised of the theory's transformational items as well as the contingent reward items was named *Transformational/Contingent Reward (TCR)*. Scale 2, comprised of both Laissez-Faire and Management-by-Exception Passive, was named *Passive-Avoidant (PA),* consistent with the naming convention used by Avolio et al. (1999) in previous analyses of the MLQ. All of the items of Management-by-Exception (Active) loaded onto Scale 3; correspondingly, the scale was named *Active Management-by-Exception* (MEA) to reflect the fact that this scale maintained the same dimensions as the original MLQ factor.

Pilot study data collection indicated that the round robin format of the 36-item survey resulted in survey fatigue. The length of the survey may have decreased the overall response rate, consistent with the assertions of Grunspan et al. (2014) who explain how survey fatigue is a heightened concern for network studies. The round-robin type surveys used in network studies can be more taxing as students must rate all network members rather than just themselves. Time to complete the full survey ranged from 11 to 27 minutes. Anecdotal comments from students who completed the survey identified survey fatigue as a concern, especially for larger teams. At one institution, 49% of responses were incomplete despite indications that the students opened the survey and viewed the round-robin questions. Factor analysis could only be accomplished using complete survey responses.

To help remedy the low response rates Novoselich and Knight (2015) sought a subset of the 36 MLQ leadership descriptive statements that could adequately represent the three-scale model that emerged from the data. Preserving the structure of the Full Range of Leadership model, reducing the survey length, strength of factor loadings, resulting Cronbach's alpha values, and face validity were considered in that order. The leadership descriptive statements were rank ordered and grouped based on their highest factor loadings to conduct the analysis (Table A.1) and associated overall scale Cronbach's alpha and alpha-if-item-deleted values for each variable are displayed.

Table A.1: MLQ survey items with factor loadings and alpha values.

		Scale			**Alpha**	**Alpha**	**Alpha**
Original Scale	**Item***	**1**	**2**	**3**	**0.95**		
Transformational	IC 31	**0.84**	0.04	0.05	**0.95**		
Transformational	IS 32	**0.79**	0.01	0.08	**0.95**		
Transformational	IS 30	**0.79**	0.05	0.01	**0.95**		
Transformational	IM 26	**0.75**	-0.03	-0.04	**0.95**		
Transformational	IM 36	**0.75**	-0.03	0.05	**0.95**		
Transactional	CR 35	**0.72**	0.00	-0.01	**0.95**		
Transformational	IIB 14	**0.71**	0.01	-0.07	**0.95**		
Transactional	CR 16	**0.70**	0.04	-0.08	**0.95**		
Transformational	IIA 10	**0.70**	-0.09	0.03	**0.95**		
Transformational	IC 15	**0.68**	0.00	-0.04	**0.95**		
Transformational	IIB 34	**0.66**	0.00	-0.15	**0.95**		
Transformational	IIA 21	**0.65**	-0.26	0.06	**0.95**		
Transformational	IIA 25	**0.63**	-0.12	-0.06	**0.95**		
Transformational	IM 9	**0.60**	-0.03	-0.02	**0.95**		
Transformational	IS 8	**0.60**	-0.04	0.05	**0.95**		
Transformational	IM 13	**0.59**	-0.11	-0.15	**0.96**		
Transformational	IIA 18	**0.57**	-0.20	-0.10	**0.95**		
Transformational	IC 19	**0.53**	-0.05	0.06	**0.95**		
Transactional	CR 1	**0.49**	-0.28	-0.03	**0.95**		
Transformational	IS 2	**0.48**	-0.28	-0.06	**0.95**		
Transformational	IC 29	**0.48**	0.23	-0.03	**0.95**		
Transactional	CR 11	**0.47**	-0.15	-0.16	**0.95**		
Transformational	IIB 23	**0.46**	-0.07	-0.24	**0.95**		
Transformational	IIB 6	**0.36**	0.10	-0.31	**0.95**		
						0.76	
Laissez Faire	LF 5	-0.09	**0.66**	0.11		**0.72**	
Transactional	MEP 12	-0.08	**0.62**	0.09		**0.72**	
Transactional	MEP 3	-0.01	**0.59**	0.08		**0.72**	
Laissez Faire	LF 7	-0.12	**0.55**	0.08		**0.73**	
Laissez Faire	LF 28	-0.18	**0.51**	0.07		**0.73**	
Laissez Faire	LF 33	-0.02	**0.49**	0.09		**0.74**	
Transactional	MEP 20	-0.14	**0.38**	-0.13		**0.75**	
Transactional	MEP 17	0.11	**0.26**	-0.15		**0.79**	
							0.76
Transactional	MEA 24	-0.05	-0.06	**-0.79**			**0.67**
Transactional	MEA 22	-0.05	-0.12	**-0.73**			**0.65**
Transactional	MEA 27	0.12	0.01	**-0.65**			**0.68**
Transactional	MEA 4	0.21	0.03	**-0.34**			**0.78**

(Novoselich & Knight, 2015), used with permission.
Note (*): IC=Individualized Concern; IA= Idealized Influence (Attributed); IB=Idealized Influence (Behavior); IM=Inspirational Motivation; IS=Intellectual Stimulation; LF=Laissez Faire; CR=Contingent Reward; MEA=Management by Exception (Active); MEP=Management by Exception (Passive)

Table A.1 indicated that consideration of factor loadings and Cronbach's alpha values were sufficient for survey item reduction. For the majority of the 36 survey items, the corresponding alpha if item deleted values (above 0.70) indicated that the scale would still be reliably measured if that item was deleted. The research team reviewed all survey items for face validity (Gall et al., 2007) to ensure alignment with the new constructs. Analysis of scale 1 indicated that maintaining the highest loading item from each of the six MLQ factors present in the scale would ensure strong factor loadings (over 0.695), decrease the scale to six items, and maintain at least one measurement of each factor. For scale 2, the four highest loaded items provided equal representation of both the laissez-faire scale and passive management by exception factor within the scale as well as maintaining an alpha value greater than 0.70. For scale 3, the presence of only four items combined with coefficient alpha values below 0.70 if any variable other than item MEA 4 were deleted resulted in the decision to maintain all four items. Overall, these reductions reduced the original 36-item survey length down to 14 items. Table A.2 shows the final exploratory factor analysis results reported in Novoselich and Knight (2015), consisting of the 14 MLQ items that were finally selected.

Table A.2: Reduced item EFA results

Scale Name	Original Scale	Item	Scale 1	Scale 2	Scale 3	Alpha
Transformational/ Contingent Reward	**Transformational**	IC 31	**0.80**	0.00	0.01	0.88
	Transformational	IS 32	**0.77**	-0.06	-0.01	
	Transformational	IM 26	**0.74**	0.05	-0.03	
	Transactional	CR 35	**0.71**	0.03	-0.01	
	Transformational	IIB 14	**0.64**	0.08	-0.03	
	Transformational	IIA 10	**0.67**	-0.01	-0.06	
Active Management by Exception	**Transactional**	MEA 22	-0.11	**0.79**	-0.08	0.76
	Transactional	MEA 27	0.13	**0.65**	0.04	
	Transactional	MEA 4	0.16	**0.37**	0.06	
	Transactional	MEA 24	-0.04	**0.78**	-0.03	
Passive-Avoidant	**Laissez-Faire**	LF 5	-0.08	-0.01	**0.64**	0.76
	Transactional	MEP 12	-0.01	0.03	**0.71**	
	Transactional	MEP 3	0.06	-0.01	**0.68**	
	Laissez-Faire	LF 7	-0.07	-0.03	**0.56**	

(Novoselich & Knight, 2015), used with permission.
*IC=Individualized Concern; IA= Idealized Influence (Attributed); IB=Idealized Influence (Behavior); IM=Inspirational Motivation; IS=Intellectual Stimulation; LF=Laissez Faire; CR=Contingent Reward; MEA=Management by Exception (Active); MEP=Management by Exception (Passive)

In this final exploratory analysis, eigenvalues supported a three-scale structure from the 14 individual items. All three scales provided adequate reliability with Cronbach's alpha greater than 0.70 (Cortina, 1993). These 14 items comprised the leadership descriptive statements incorporated in the current study.

Appendix B: Scale Variable Summary

Table B.1: Leadership and Member Effort Scale Variable Summary

<table>
<tr><th colspan="3">Leadership Skills Scale</th></tr>
<tr><th colspan="2">Rate your ability to:[1]</th><th>Cronbach's Alpha</th></tr>
<tr><td colspan="2">Identify team members' strengths/weaknesses and distribute tasks and workload accordingly.</td><td rowspan="6">0.89</td></tr>
<tr><td colspan="2">Monitor the design process to ensure goals are being met.</td></tr>
<tr><td colspan="2">Help your group or organization work through periods when ideas are too many or too few.</td></tr>
<tr><td colspan="2">Develop a plan to accomplish a group or organization's goals.</td></tr>
<tr><td colspan="2">Take responsibility for group's or organization's performance.</td></tr>
<tr><td colspan="2">Motivate people to do the work that needs to be done.</td></tr>
<tr><th colspan="3">Member Effort Scale</th></tr>
<tr><th>Original Question</th><th>Adapted Question[2]</th><th>Cronbach's Alpha</th></tr>
<tr><td>You always put as much effort as possible into your work.</td><td>I always put as much effort as possible into my work on this design project.</td><td rowspan="5">0.93</td></tr>
<tr><td>You are highly committed to do the best job you can.</td><td>I am highly committed to do the best job I can on this design project.</td></tr>
<tr><td>For you, a good day at work is one in which you have performed to your utmost.</td><td>To me, a good work day is one in which I have performed to my utmost.</td></tr>
<tr><td>You try to work as hard as you can.</td><td>I try to work as hard as I can on this design project.</td></tr>
<tr><td>You intentionally expend a great deal of effort in doing your job.</td><td>I intentionally expend a great deal of effort on my academic work.</td></tr>
</table>

[1]1: Weak/none; 2: Fair; 3: Good; 4: Very Good; 5: Excellent

[2]Likert scale: 1: Strongly Disagree; 2: Disagree; 3: Neither Agree nor Disagree; 4: Agree; 5: Strongly Agree

Appendix C: Midpoint Confirmatory Factor Analysis Results.

To further investigate the three-scale leadership model that emerged from the data, a second confirmatory factor analysis was conducted on the responses to the first round of the survey which occurred at the midpoint of the design experience (Table C.1). 94.8% of the total population were ME students with 3.2% EE/CS, 0.4% GEN, and 1.5% Other. At the large research university, 4.1% of the students identified themselves as a member of the Corps of Cadets. Missing data were again excluded list-wise and comprised 4.8% of the midpoint sample. Analysis procedures were identical to those used for the course end data. Results for this model also indicate good fit of the model to the observed data (Table C.4). These results provide indications that the model provides a stable explanation of leadership behaviors within the capstone design teams across the length of the design experience. A total of 294 students provided responses to both the midpoint and course-end surveys, representing 65.7% and 68.8% of the total round one and round two samples respectively.

Table C.1: Midpoint Data Demographics

Site	2014 ME Bachelor's Degree Awarded/ Sample Size	Black	Asian	Hispanic	Native American	Pacific Islander	White	Multi-Race	Race Not-reported	Inter-national	Inter-national Not Reported	Male	Female	Sex Not Reported
Site A midpoint	322 (99.4%)	2.2%	8.1%	5.6%	0.3%	0.0%	78.9%	4.7%	1.2%			90.7%	9.0%	0.3%
Site B midpoint	114 (83.21%)	3.5%	4.4%	7.0%	0.0%	0.0%	81.6%	3.5%	0.0%			87.7%	12.3%	0.0%
Site C midpoint	29 (19.33%)	3.4%	6.9%	0.0%	3.4%	3.4%	79.3%	3.4%	0.0%			93.1%	6.9%	0.0%
Total	465	2.6%	7.1%	5.6%	0.4%	0.2%	78.9%	4.3%	0.9%			90.1%	9.7%	0.2%
National[1]	25042	2.4%	7.8%	8.5%	0.3%	0.2%	63.9%		0.0%	6.2%		87.2%	12.8%	

Table C.2: Midpoint Data Covariance Matrix

	MEP3	MEA4	LF5	LF7	IIA10	MEP12	IIB14	MEA22	MEA24	IM26	MEA27	IC31	IS32	CR35
MEP3	1.16													
MEA4	0.16	1.78												
LF5	0.67	0.03	0.98											
LF7	0.55	0.04	0.55	0.85										
IIA10	-0.43	0.38	-0.42	-0.37	1.73									
MEP12	0.75	0.08	0.63	0.54	-0.42	0.97								
IIB14	-0.49	0.32	-0.46	-0.38	0.88	-0.45	1.52							
MEA22	-0.23	0.52	-0.26	-0.24	0.42	-0.23	0.70	1.82						
MEA24	-0.30	0.51	-0.30	-0.24	0.52	-0.29	0.84	1.12	1.83					
IM26	-0.52	0.26	-0.50	-0.43	0.86	-0.50	1.11	0.76	0.93	1.58				
MEA27	-0.18	0.67	-0.22	-0.19	0.51	-0.16	0.79	1.01	1.10	0.86	1.82			
IC31	-0.52	0.31	-0.49	-0.39	1.00	-0.50	1.14	0.73	0.92	1.22	0.93	1.81		
IS32	-0.46	0.21	-0.45	-0.38	0.79	-0.43	0.99	0.73	0.79	1.09	0.84	1.16	1.56	
CR35	-0.39	0.19	-0.39	-0.37	0.78	-0.39	0.90	0.64	0.77	0.99	0.73	1.11	1.00	1.49

Table C.3: Midpoint Data Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
						Statistic	Error	Statistic	Error
MEP3	3299	1.0	5.0	1.768	1.079	1.381	0.043	1.090	0.085
MEA4	3299	1.0	5.0	2.473	1.333	0.408	0.043	-1.013	0.085
LF5	3299	1.0	5.0	1.555	0.991	1.844	0.043	2.638	0.085
LF7	3299	1.0	5.0	1.507	0.921	1.980	0.043	3.467	0.085
IIA10	3299	1.0	5.0	3.495	1.314	-0.481	0.043	-0.869	0.085
MEP12	3299	1.0	5.0	1.665	0.985	1.561	0.043	1.954	0.085
IIB14	3299	1.0	5.0	3.628	1.232	-0.523	0.043	-0.713	0.085
MEA22	3299	1.0	5.0	3.142	1.351	-0.123	0.043	-1.120	0.085
MEA24	3299	1.0	6.0	3.076	1.354	-0.079	0.043	-1.163	0.085
IM26	3299	1.0	5.0	3.583	1.259	-0.508	0.043	-0.791	0.085
MEA27	3299	1.0	5.0	2.994	1.349	-0.006	0.043	-1.117	0.085
IC31	3299	1.0	5.0	3.387	1.344	-0.328	0.043	-1.051	0.085
IS32	3299	1.0	5.0	3.459	1.248	-0.400	0.043	-0.796	0.085
CR35	3299	1.0	5.0	3.804	1.220	-0.796	0.043	-0.302	0.085

Table C.4: CFA Model Summary

	Midpoint Data
Number of Cases	3299
RMSEA	0.06 (<0.6-0.8)
95% CI	0.057-0.064
Tucker-Lewis NNFI (TLI)	0.96 (> 0.95)
CFI	0.97 (>0.95)

Table C.5: Reliability Analysis using Cronbach's Alpha

Scale	**Midpoint N=3299**
Transformational/Contingent Reward	Alpha=0.91
Active Management by Exception	Alpha=0.77
Passive-Avoidant	Alpha=0.87

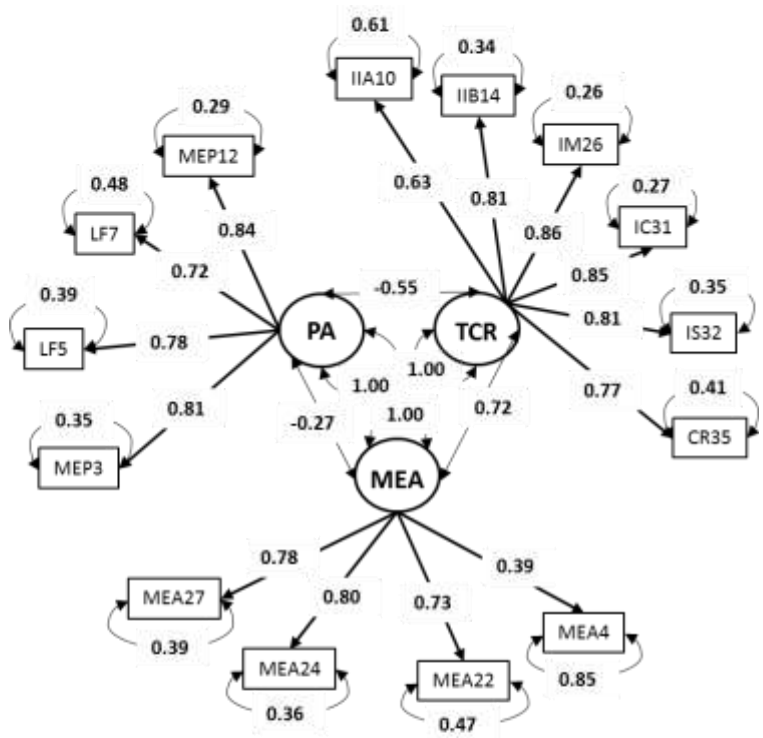

Figure C.1. Path Diagram for the Midpoint Model (Standardized Coefficients).

Table C.6: Unstandardized Parameter Estimates of Round 2 CFA model.

Parameter	Estimate	Std Error	z Value	Pr(>|z|)
TRANSFORMATIONAL/CONTINGENT REWARD->IIA10	0.82	0.02	42.44	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD->IIB14	1.00	0.02	60.73	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD->IM26	1.08	0.02	65.91	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD->IC31	1.15	0.02	65.26	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD->IS32	1.01	0.02	60.19	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD->CR35	0.94	0.02	55.85	0.00E+00
IIA10<->IIA10	1.05	0.02	41.99	0.00E+00
IIB14<->IIB14	0.51	0.01	37.32	7.83E-305
IM26<->IM26	0.42	0.01	34.38	4.70E-259
IC31<->IC31	0.49	0.01	34.83	9.19E-266
IS32<->IS32	0.54	0.01	37.56	0.00E+00
CR35<->CR35	0.61	0.02	39.15	0.00E+00
TRANSFORMATIONAL/CONTINGENT REWARD<->ACTIVE_MANAGEMENT_BY_EX(	0.72	0.01	70.93	0.00E+00
ACTIVE MANAGEMENT BY EXCEPTION->MEA4	0.52	0.02	23.36	1.04E-120
ACTIVE MANAGEMENT BY EXCEPTION->MEA22	0.98	0.02	49.09	0.00E+00
ACTIVE MANAGEMENT BY EXCEPTION->MEA24	1.09	0.02	56.01	0.00E+00
ACTIVE MANAGEMENT BY EXCEPTION->MEA27	1.05	0.02	54.00	0.00E+00
MEA4<->MEA4	1.51	0.04	42.85	0.00E+00
MEA22<->MEA22	0.86	0.02	35.09	1.07E-269
MEA24<->MEA24	0.65	0.02	29.35	2.55E-189
MEA27<->MEA27	0.71	0.02	31.32	2.29E-215
ACTIVE MANAGEMENT BY EXCEPTION<->PASSIVE AVOIDANT	-0.27	0.02	-15.03	4.57E-51
PASSIVE AVOIDANT->MEP3	0.87	0.01	58.34	0.00E+00
PASSIVE AVOIDANT->LF5	0.78	0.01	55.72	0.00E+00
PASSIVE AVOIDANT->LF7	0.66	0.01	49.45	0.00E+00
PASSIVE AVOIDANT->MEP12	0.83	0.01	61.65	0.00E+00
MEP3<->MEP3	0.40	0.01	32.29	1.02E-228
LF5<->LF5	0.38	0.01	34.28	1.70E-257
LF7<->LF7	0.41	0.01	37.63	0.00E+00
MEP12<->MEP12	0.29	0.01	29.12	2.04E-186
TRANSFORMATIONAL/CONTINGENT REWARD<->PASSIVE AVOIDANT	-0.55	0.01	-42.19	0.00E+00

Appendix D: Independence Assumption Verification Experimental Results

Follow-on confirmatory factor analyses indicated that the use of all individual leadership rating dyads had no appreciable impact on model fit. Because the round-robin data collection format had the potential to violate the independent case assumption of confirmatory factor analysis, an experiment was conducted to determine the degree to which multiple ratings from individual team members affected model fit. In round-robin data collection, each team member rates all other team members. When using all cases in data analyses, the underlying assumption is that each rater to ratee relationship is a separate case; there is a potential to violate the case independence assumption of confirmatory factor analysis in that each team member provides multiple team member ratings. To assess this potential violation, 1000 iterations of confirmatory factor analysis were conducted on subsets of the full data set that included only one randomly selected team member rating across all 14 leadership descriptive statements from each student survey response. Mean goodness of fit scores across the 1000 iterations are compared with the full data model fit indices in Table D.1. Because the mean of most fit indices remained within acceptable good fit cutoff values, the experiment indicates that the inclusion of all individual dyads did not significantly skew results.

Table D.1: Random Sample Experiment Results

	Model	**Random Samples**	**Cutoff[1]**
RMSEA	0.06	0.06	<0.06-0.08
NNFI (TLI)	0.96	0.96	>0.95
CFI	0.97	0.97	>0.95

[1]Note: King et al. (2006) good fit cutoff values presented.

Appendix E: Site Comparison of Final Project Assignments

A detailed analysis of the design presentation and design report assignments revealed that using course grades as a measure of task performance across the three research sites was appropriate. Results of the analyses showed that the teams' grades were measuring similar requirements and were comparable across the three research sites. Although the teams were nested in separate institutions with a separate grading rubrics, there was enough commonality in assignment expectations across the research sites to deem use of course grades appropriate for measuring task performance.

For all three sites, the final design requirements were graded at the team level and had a similar percentage contribution to the spring semester course grade. At site A, the final design report represented 15% of the course grade and was graded using a site-specific standardized rubric with input from both the client and a graduate teaching assistant called the engineering manager. The final design presentation represented 10% of the course grade. At site B, the final design report represented 20% of the course grade, and unlike the other two institutions, the site B report was graded in two iterations using a site-specific standardized rubric. The preliminary evaluation included input from the faculty advisor and project sponsor. The team was then able to revise the report prior to the secondary evaluation which included both the faculty advisor and course coordinator. At site B, the final presentation also comprised 20% of the course grade. At site C, the final design report and presentation comprised 22.5% and 15% of the final course grade, respectively. The final design report was generally graded only by the faculty advisor at site C, using a site-specific standardized rubric. Faculty advisors may solicit feedback from the client in the grading process at site C., but it was not routine. Across all three institutions, the final presentations were graded using a combination of judging panels and faculty advisor input from their observations of the final presentation using site specific grading rubrics.

Although teams were evaluated using site specific grading rubrics, a comparison of the grading rubrics identified commonality in course requirements. The results indicated that the teams were graded on similar criteria (see Tables E.1 and E.2). In Table E.1, sites A and B differed only slightly from site C in final presentation requirements. Site A did not require evaluation of question and answer sessions, or lessons learned from the project. Both sites A and B also did not evaluate the team's use of project management. Table E.2 shows a high degree of commonality among the three research sites with regards to the final report. Because of the large number of unique rubric topics at sites B and C, these unique items were consolidated in Table E.3, which shows that these unique topics in the final report rubrics accounted for between 8 and 12% of the grade at sites B and C, respectively; 88-92% of topics across the three research sites were common.

To alleviate potential differences in team scores that may have resulted from institution level differences, we converted the raw final presentation and final report grade percentages into z-scores by institution, similar to the methods employed by Stump et al. (2014) in their analysis of student intelligence beliefs across multiple courses. This transformation preserved ranking within the site groupings but removed between-site variation (Coladarci, 2004).

Table E.1: Final Presentation Rubric Similarities Across Research Sites

Final Presentation Rubric	**Site A[1]**	**Site B[2]**	**Site C[3]**
Technical Content			
Effectively communicate design problem. Explain chosen solution method.	✓	✓	✓
Use of analytical methods to generate/refine design.	✓	✓	✓
Success of design in meeting customer needs/design problem.	✓	✓	✓
Sufficient development of design to allow prototyping and operation.	✓	✓	✓
Validation of design through testing, modeling, and prototyping.	✓	✓	✓
Ability of completed design to meet project requirements	✓	✓	✓
Lessons learned and future development.		✓	✓
Use of project management to effectively use resources.			✓
Presentation Delivery			
Organization, design, and effectiveness of presentation.	✓	✓	✓
Clear communication, clarity, content, and engagement by presenter.	✓	✓	✓
Effective communication of technical material to audience.	✓	✓	✓
Discussion/answers to questions		✓	✓

[1]5 point scale: 1: Poor; 2: Fair; 3: Good; 4: Very Good; 5: Excellent (Common Rubric)
[2]5 point scale: 1: Poor; 2: Marginal; 3: Fair; 4: Good; 5: Excellent (Common Rubric)
[3]Audience: 4 point scale: 1: Unsatisfactory; 2: Below Expectations; 3: Meets Expectations; 4: Exceeds Expectations. Mentor (Faculty Advisor): 3 point scale:1: Unsatisfactory; 2: Below Expectations; 3: Meets Expectations

Table E.2: Final Report Rubric Similarities Across Research Sites.

Final Report Rubric Similarities	**Site A**	**Site B**	**Site C**
Technical Content			
Front Matter (Title Page, Executive Summary, etc.)	✓	✓	✓
Problem Statement/ Definition	✓	✓	✓
Customer Need Identification	✓	✓	✓
Design Concepts/Background Research	✓	✓	✓
Concept Evaluation and Selection	✓	✓	✓
Embodiment Design	✓	✓	✓
Prototype Test Plan/ Testing Results	✓	✓	✓
Technology Readiness/Future Work Recommendations	✓	✓	✓
Budget/Cost Analysis	✓	✓	✓
References	✓	✓	✓
Engineering Drawings	✓	✓	✓
Prototype Test Matrices	✓	✓	✓
Project Summary (customer summary)	✓	✓	✓
Report Writing			
Formatting and Style	✓	✓	✓

Table E.3: Unique Final Report Rubric Elements by Research Site.

Final Report Rubric Differences	**Site A**	**Site B**†	**Site C**†
Technical Content			
STEP-Lifecycle Analysis		4%	
Applicable Standards		4%	
Summary of customer deliverables			1%
Project Management			2%
Team Charter/Team Structure			1%
Project Management Gantt Chart			1%
Closeout Memos (post project reflection)			4%
Quad Chart (PowerPoint project summary)			3%

†Percentage of Grade

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