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Relating Shared Leadership to Capstone Team Effectiveness*

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Waning student engagement over the course of year-long capstone design projects may decrease team effectiveness and create challenges for capstone faculty advisors and student team leaders. Because leadership is an influence process, reframing how leadership is conceptualized for students may provide a tool that can bolster student effort and overall team effectiveness. Recent literature suggests that sharing leadership may be more effective than vertical leadership for complex design work, but little is known regarding shared leadership within the undergraduate engineering context. This study examined the relationship between shared leadership and team effectiveness for undergraduate mechanical engineering capstone design teams using an adaptation of the Full Range of Leadership model. Results indicated that the overall strength and a limited sharing of select team leadership behaviors relate to a team's effectiveness through group process and individual satisfaction, but not task performance. This study provides capstone faculty with insights into effective leadership behaviors that may be encouraged within the capstone design experience.

Keywords: engineering leadership; capstone design; team effectiveness; teamwork

1. Introduction

Capstone design courses can be challenging for students because of their project-based, open-ended and collaborative nature, leading to waning student effort. When faced with such challenging academic work, students may attempt to negotiate less demanding requirements [1]. Over the course of a semester or quarter, this degradation in effort may decrease team effectiveness.

The applied nature of capstone projects, where a prototype design must perform for a customer, separates capstone courses from conventional classroom environments and requires increased self-directed learning from students. As a result, both faculty and students undergo a learning process in real-time. Faculty do not necessarily know how to address the design problem [2] or have the knowledge to navigate various team issues [3]; thus, students may be forced to navigate some of these challenges on their own. Sustaining self-directed learning may require additional support from faculty or team advisors [4].

Helping shape leadership behaviors may be one way to mitigate this potential decline in team effectiveness. Yukl [5] asserts that leaders may improve team performance by influencing team processes in positive ways. Stagl et al. [6, p. 172] summarize work in team leadership research and find that, "the totality of research supports this assertion; team leadership is critical to achieving both affective and behaviorally based team outcomes." Empirically, leadership has shown to predict team outcomes such as team effectiveness and team performance (e.g., [7]) in a wide variety of contexts outside of engineering design.

One potential barrier to shaping leadership behaviors for engineering students may be the view that leadership within engineering programs is best left to extra-curricular settings [8–10]. Currently, leadership is not widely perceived as an integral skill in the development of students for the engineering field. Recent literature suggests that an empirically tested model for effective leadership in a team-based engineering context does not exist [9, 11, 12]. 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, particularly for undergraduate engineering teams.

This study addresses this literature gap by investigating leadership from the perspective of the collaborative, team-based environment that engineers routinely experience [13]. 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 [14–17], 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., [14, 18]), little is known regarding the effectiveness of shared leadership for design

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teams. Building upon the prior shared leadership research of Novoselich and Knight [18], this study deepens our understanding of shared leadership in design teams by examining how sharing various forms of leadership relates to team effectiveness, measured as a combination of group process, individual satisfaction, and task performance. Specifically, the study addressed the following research question:

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

2. Review of the literature

Team leadership is a complex influence process that continues to evolve with the changing landscape of collaborative work. Traditional, hierarchical conceptualizations of leadership are giving way to more collaborative (i.e., shared) frameworks that may lead to greater team effectiveness. There is a vast literature on effective leadership behaviors, so this literature review is scoped to address the justification for considering a shared leadership framework for capstone design teams.

2.1 Effectiveness of shared leadership

Leadership literature has traditionally focused on vertical conceptualizations of leadership where one leader influences followers [16, 19, 20]. The possibility of multiple team members influencing each other has been a relatively recent development in the long history of leadership research [16]. 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 [15]. This scenario aligns with Newstetter's [21] description of student learning environments in engineering design teams as well as Salas et al.'s [6] integrative model of team effectiveness, which references team leaders (plural) as opposed to team leader (singular) and describes how shared cognition affects leadership and vice-versa. Considering this evolving knowledge distribution, Wageman and Gardner [22] call for a re-examination of team leadership in light of the new landscape of modern collaboration. Dorst [23] similarly calls for an examination of the context by which design is practiced, which are aims of this study.

Capstone design teams provide 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 [24]. On the cusp of professional engineering practice, these experiences are also a final opportunity to address and develop engineering professional skills, to include leadership [25, 26]. Pearce [15] 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, Pearce, & Perry [17] 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 has focused on the effectiveness of shared leadership for the design team context. For student design teams specifically, Zafft, Adams, & Matkin [27] established 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. More recently, Novoselich and Knight [18] showed that leadership in capstone design teams is most often shared rather than vertical. 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 [28] and team performance [29, 30]. Considering this literature, the following hypothesis is proposed:

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

2.2 Effective forms of leadership

The Full Range of Leadership model informs this study's investigation of shared leadership. Whereas shared leadership examines how many and to what extent individuals enact leadership within the teams, the Full Range of Leadership model explains the behaviors that comprise different forms of leadership. The Full Range of Leadership model has been in existence for over two decades with wide acceptance for validity and reliability (see [31]) and is routinely measured using the Multifactor Leadership Questionnaire (MLQ) (see [32]). Previous literature has demonstrated the applicability of the

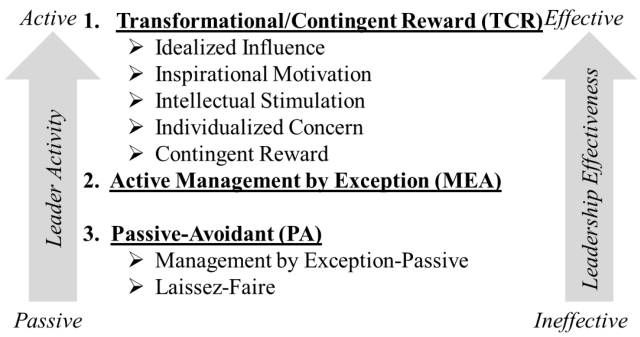

Fig. 1. ME Capstone Full Range of Leadership Model [18].

Table 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 [38]
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 [38]–[40]
Passive Avoidant (PA)	A delay in action until serious issues arise or a total absence of involvement, especially when needed [36], [38]

Full Range of Leadership model for engineering contexts (e.g., [18, 33, 34]), and links between the theory and leadership orientations within engineering professional practice have been proposed by Rottman et al. [9].

Novoselich and Knight [34] took a comprehensive look at the MLQ to construct 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), determined using a 14-item subset of the MLQ. Fig. 1 shows the ME Capstone version of the Full Range of Leadership model, which describes the progression of both leader activity and leadership effectiveness across the three leadership scales contained in the model. These scales are similar to those that Avolio et al. [35] concluded may constitute a parsimonious model of leadership in teams. Other research has also addressed similar scales (e.g., [36, 37]) outside the engineering design team context. Table 1 describes each.

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. TCR leadership behaviors are the most active and are shown to be the most effective in a variety of contexts [7, 39, 41]. MEA has been shown to exhibit both positive and negative relationships with organizational and team effectiveness [7, 39]; for engineering design teams, these behaviors positively correlated with TCR leadership [38], 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 [39]. Thus, the first hypothesis is refined as follows:

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

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

3. Data and methods

This quantitative study related shared leadership to team effectiveness using ordinary least squares regression. The shared leadership independent variables were team-level leadership network density and decentralization measures (and their interactions) developed from student-level leadership network data collected using a round-robin (360-degree) leadership survey of capstone design team students. The team effectiveness dependent variables were team-level measures derived from student survey data (groups process and satisfaction self-report measures) or capstone course deliverables (task performance, i.e., grades).

3.1 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, 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 regarding course objectives, course content, project requirements, and team-based pedagogy. The mixture of civilian and military institutions provided 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 represented 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 [42]) and access to student participants. The study had IRB approval at all three institutions.

In taking the survey, team members assessed each of their teammates' leadership behaviors based on the same 14 MLQ-derived leadership descriptive statements used by [34]. These survey items were presented in a round-robin (360-degree) format, which asked all team members to rate each of their team members as well as their faculty advisor (Fig. 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; the office of institutional research at site C administered the online survey through a different web host.

This study examined the responses from 209 students (Table 2) 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). 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.

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 to the recommendations of [43], using multiple imputation algorithms

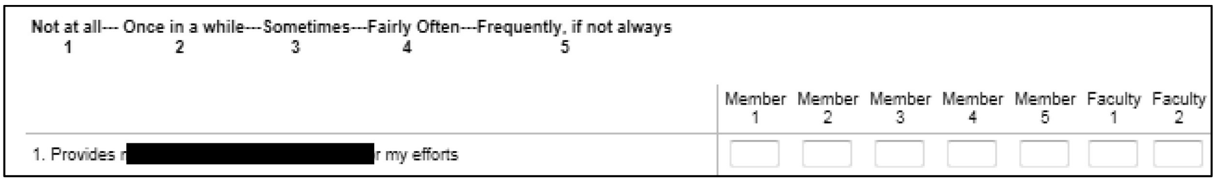

Fig. 2. Sample Round-Robin Survey Item. (Item redacted because of copyright agreements)

Table 2. 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.

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 [44]. Missing dyadic ratings were replaced by the mean rating of the rest of the team members regarding the rated individual.

3.2 Methods

To address the research question, this study used ordinary least squares regression to compare the team-level leadership network density and decentralization (and their interactions) with dependent variables of team effectiveness. The leadership network densities and decentralizations were derived from social network analyses of scale variables representing the leadership relationships between team members gathered from the student surveys. The team effectiveness dependent variables were team-level measures derived from student survey data (groups process and satisfaction self-report measures) or capstone course deliverables (task performance, i.e., grades).

3.2.1 Operationalizing shared leadership

Social network analysis methods are commonly employed to measure the shared leadership phenomenon in teams [28, 45]. Within these analyses, two measures of shared leadership are commonly calculated: 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) [45, 46]. Gockel and Werth [45] 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 Fig. 3.

Historically, researchers have focused on either decentralization or density independently [29]—this research investigates both measures simultaneously, however, following the recommendation of Gockel and Werth [45] and Mayo et al. [46]. 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 Fig. 3. Mayo et al. [46] assert that teams with both high decentralization and density in their leadership networks exhibit shared leadership.

The team member round-robin ratings provided by the student surveys were aggregated into the ME Capstone Full Range of Leadership scales identified by Novoselich and Knight [18] (TCR, MEA, and PA). The scales were analyzed at the team level to determine the network decentralization and network density using social network analyses. Network analyses were completed using the SNA package in the statistical analysis software "R". These network analyses resulted in a total of six shared leadership measures: ***TCR decentralization, TCR density, MEA decentralization, MEA density, PA decentralization,*** and ***PA density***. Table 3 provides the descriptive statistics for these six shared leadership measures along with the scale-level interactions.

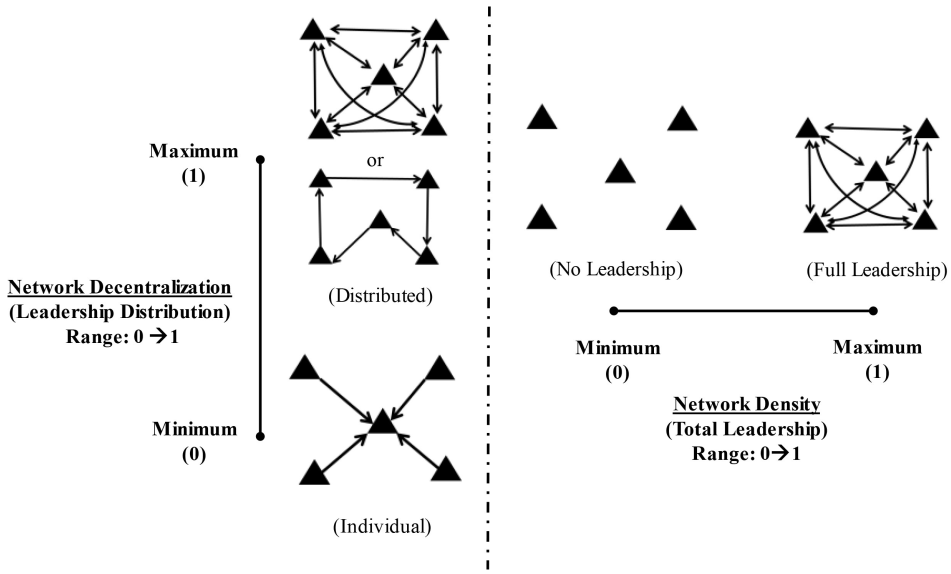

Fig. 3. Shared Leadership Measure Examples.

Table 3. Shared Leadership (Independent) Variable Descriptive Statistics

	N	Min.	Max.	Mean	Std. Dev.	Skewness Statistic	Skewness Std. Error	Kurtosis Statistic	Kurtosis 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

3.2.2 Operationalizing team effectiveness

A combination of measures was used to operationalize team effectiveness. 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 [47–49]. Wageman [48] cites Hackman [49] in her definition of three components of team effectiveness which are summarized in Table 4.

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 [3]. These components are similar to the *solution development* (product) and *learner development* (process) constructs articulated by [50] for assessment outcomes of capstone design courses. Table 5 provides descriptive statistics for the team effectiveness measures (dependent variables) which will be further discussed in the following sections.

3.2.2.1 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. [1] and Jones et al. [51] 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. [52] 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 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

Table 4. Team Effectiveness Components from [48]

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.

Table 5. Team Effectiveness Measure Descriptive Statistics

Team Effectiveness Component	Measure	N	Min.	Max.	Mean	Std. Dev.	Skewness Statistic	Skewness Std. Error	Kurtosis Statistic	Kurtosis 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

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 restrictions, the actual items of this scale cannot be published.

3.2.2.2 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 found that, "students who were the most satisfied with college put the most into it and got the most out of it." [53, p. 33]. Studies have also shown that students' satisfaction with collaborative learning experiences positively effect subjective measures of their learning (e.g., [54]). Examining student satisfaction with the teaming experience can provide indications as to whether the teaming experience is conducive to a positive learning environment.

Avolio et al. [52] also found that team member satisfaction relates positively to levels of transformational and transactional leadership and negatively 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. Actual items cannot be published because of copyright reasons.

3.2.2.3 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. [27], who used final 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 [55], who assert the inadequacy of the design report to evaluate both teaming skills and technical skills. The design presentation was 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.

Several 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 rubric, 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 et al. [56], to ensure comparability.

3.2.3 Control variables

To account for potential relationships that may provide alternate explanations of team effectiveness, we controlled for *team size, team engineering GPA, 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 limited the number of variables that could be included in regression analyses.

Team size refers to the number of students assigned to each design team. This variable was based on the student team rosters established in the course at the beginning of the fall semester and 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.

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., [57, 58]). 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 as calculated using Blau's index of diversity (see [59]).

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).

A 6-item leadership skills scale measured students' self-reported leadership skills (Table 6). 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 [60]). For the current sample, the mean of these six items comprised a single scale variable ($\alpha = 0.89$) at the individual level. The mean team member scores characterized the average level of leadership skills within the team (team leadership skills).

3.3 Relating shared leadership to team effectiveness

Ordinary least squares (OLS) regression addressed the research question. Consistent with the recommendations of Keith [62], the main effects and interaction effects of the density and decentralization measures were investigated across the TCR, MEA, and PA forms of leadership 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.

A follow-up bootstrapping analysis evaluated 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 [61, 62]. To evaluate the robustness of the relationships, a 10,000-dataset bootstrapping analysis of the best-fitting OLS regression model was conducted 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 the confidence that the identified relationship would hold for a larger population of capstone design teams.

Evaluating model fit took into consideration the variance explained by the models adjusted for the degrees of freedom (adjusted R^2), Akaike's Information Criterion (AIC) [63], and the Bayesian Information Criterion (BIC) [64]. Including these multiple criteria allowed for better assessment of the complexity of the regression models [61, 65]. The variance explained by the regression model tends to increase as additional variables are considered [61] 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

Table 6. Items Comprising the Leadership Skills Scale ($\alpha = 0.89$)

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.

parameters) [61]. For both AIC and BIC, smaller values indicate a better model fit [61, 65]. Incorporating all these criteria allowed for assessment of the most parsimonious model.

3.4 Limitations

Several limitations should be considered 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 [65]. This limited sample can be attributed to the challenges inherent to collecting full-team network data from students [66]. Ideally, the significant relationships determined through exploratory analysis in this paper should be tested on another set of data [65]. 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. [27], 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 may be unwarranted. The capstone design context does not fully replicate professional practice because capstone design team students are peers with relatively similar engineering experience and little difference in seniority or position in a hierarchical structure. These dynamics may alternate the relationships found here in a professional engineering context.

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 response rates, as discussed in Novoselich and Knight [34]. 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.

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 [67]. As raters of other team members' leadership behaviors, students may feel threatened by the survey process [27]. 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 [68], 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 [67].

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.

4. Results

This study resulted in four parsimonious regression models that illuminate relationships between shared leadership within the team and measures of team effectiveness. The results indicate partial support for the hypotheses; TCR, MEA, and PA leadership relates to the team effectiveness measures of group process and satisfaction, but not task performance.

4.1 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. This examination considered 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 7). 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 ($\tau + \sigma^2$) [69]. Intra-class correlations were calculated using the MIXED procedure in SPSS v23 as explained by Peugh and Enders [70]. Because of the small number of level 2 groupings, the residual maximum likelihood method (REML) was used following the recommendations of Snijders and Bosker [69] for models with less than 50 level 2 groupings. The final presentation and final report z

Table 7. 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

scores were not examined as the site level variation in these two variables was mitigated by conversion to z scores.

Intra-class correlations indicated that both team effectiveness measures showed little level 2 between-group variance (Table 8). 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 [61, 71, 72].

4.2 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* (Table 8). 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 [62]. 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*. 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*

Table 8. Extra Effort Scale Regression Model Summary

N=45	Extra Effort Scale†									Bootstrap
	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=0.00)**
TCR Decentralization	**-0.27***	**-0.40*** **					**-0.35** **		**-0.26***	**0.01 (p=0.00)**
TCR Density	**0.92*** **	**0.94*** **					**0.87*** **		**0.72*** **	**0.04 (p=0.00)**
INT TCR Decen Dens		**-0.27** **					**-0.23***		**-0.18***	**-0.29 (p=0.01)**
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	
PA Decentralization					0.18	0.19				
PA Density					-0.27	-0.29				
INT PA Decen Dens						-0.04				
Control Variables†††								**Yes**	**Yes**	
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.
††† Control Variables: team size, team engineering GPA, engineering GPA diversity, team sex, team leadership skills.
\+ Parsimonious Model.
* = $p \leq 0.05$; ** = $p \leq 0.01$; *** = $p \leq 0.001$.

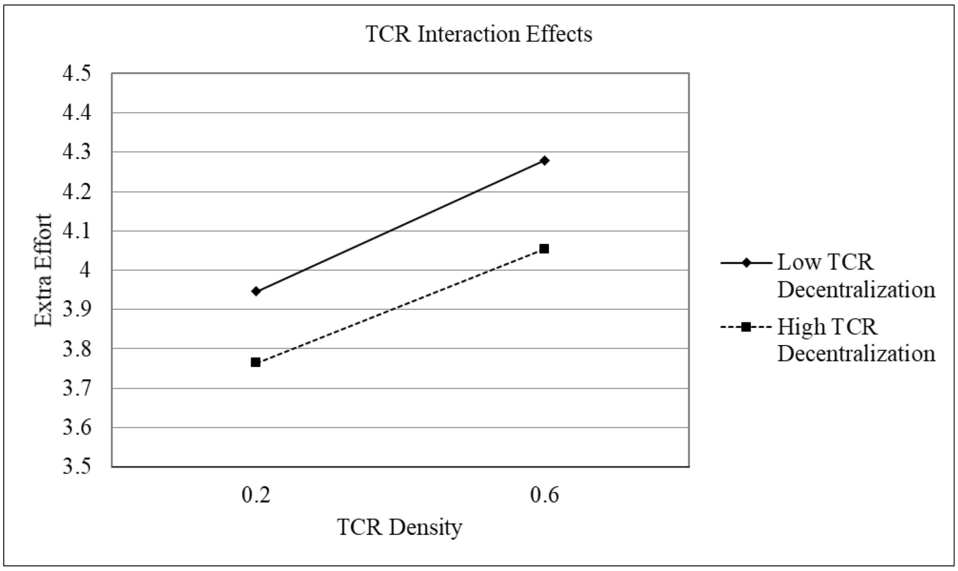

Fig. 4. Interaction Effects of TCR Leadership Relationship with *Extra Effort*.

effort (models 5 and 6). Among the control variables, only *team leadership skills* showed a significant relationship with *extra effort*.

These analyses show that shared TCR leadership relates to *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 (Fig. 4). 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.

4.3 Individual satisfaction results

Examining regression models for the *satisfaction* scale showed that TCR and PA leadership significantly related to *satisfaction* (Table 9). 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-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 [62] and were not included in more complex models. The parsimonious model (model 7) minimized AIC and 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.

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 [52] results.

4.4 Task performance results

Regression model results for both final report grade and final presentation grade z scores exhibited no

Table 9. Satisfaction Scale Regression Model Summary

N=45	Satisfaction Scale†									Bootstrap
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7+	Model 8	Model 9	Bias/Sig.††
Constant	**4.09*** **	**4.11*** **	**4.09*** **	**4.06*** **	**4.09*** **	**4.06*** **	**4.09*** **	**4.09*** **	**4.09*** **	**-0.00 (p=0.00)**
TCR Decentralization	-0.17	**-0.21***					**-0.24****		-0.17	**-0.01 (p=0.01)**
TCR Density	**0.94*** **	**0.95*** **					**0.86*** **		**0.75*** **	**-0.06 (p=0.00)**
INT TCR Decen Dens		-0.07								
MEA Decentralization			**0.42****	**0.48*** **			0.12		0.12	-0.00 (p=0.11)
MEA Density			**0.39****	**0.35***			0.01		-0.00	0.018 (p=0.92)
INT MEA Decen Dens				-0.24						
PA Decentralization					0.05	0.07	-0.03		0.03	-0.00 (p=0.82)
PA Density					**-0.45***	**-0.48***	-0.24		-0.14	**-0.27 (p=0.04)**
INT PA Decen Dens						-0.07				
Control Variables†††								**Yes**	**Yes**	
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.
††† Control Variables: team size, team engineering GPA, engineering GPA diversity, team sex, team leadership skills.
+ Parsimonious Model.
* = p ≤ 0.05; ** = p ≤ 0.01; *** = p ≤ 0.001.

Table 10. Final Report Grade Regression Model Summary

N=44	Final Report Grade†								
	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
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							
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					
PA Decentralization					-0.22	-0.19			
PA Density					-0.18	-0.25			
INT PA Decen Dens						-0.14			
Control Variables†††								**Yes**	**Yes**
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).
††† Control Variables: team size, team engineering GPA, engineering GPA diversity, team sex, team leadership skills.
+ Parsimonious Model.
* = p ≤ 0.05.

Table 11. 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
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							
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					
PA Decentralization					-0.06	-0.07			
PA Density					-0.17	-0.13			
INT PA Decen Dens						0.07			
Control Variables								**Yes**	**Yes**
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).
††† Control Variables: team size, team engineering GPA, engineering GPA diversity, team sex, team leadership skills.
+ Parsimonious Model.
* = p≤0.05.

significant relationships between shared leadership and measures of task performance. Table 10 shows that only *team eng. GPA* had a statistically significant, positive relationship with *final report grade* (model 8). In Table 11, no statistically significant relationships were identified for *final presentation grade*.[1]

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. 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.

[1] For these analyses, one team was deleted casewise. As sub-teams of a larger capstone design project, two of the 45 teams contributed to the same final design report and presentation. Only one team was retained to maximize the amount of data available for analysis.

4.5 Analysis

Results partially support the overall hypothesis, which anticipated a positive relationship between shared leadership and team effectiveness (Table 12). Leadership, when distributed across a limited number of team members, positively related 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. [28] 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

Table 12. Hypothesis Summary

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

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* tended to decrease. The descriptive statistics of the shared leadership network measures shown in Table 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 emanated from multiple team members, albeit a limited number. Correspondingly, these results suggest there may be an optimal model that is characterized by 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, additional investigation of task performance is warranted before adequate claims can be made regarding this facet of team effectiveness.

Hypotheses A and B were also partially supported. For hypothesis A, the amount (i.e., density) of TCR leadership showed robust, positive relationships for *extra effort*, moderated by distribution (i.e., decentralization). The moderating effect 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 [15] 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. [46] 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, *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 [15] 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. [28] 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 B, 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 [73], and workload distribution is a common source of student engineering team conflict [74]. Students seem to be more satisfied when the teams' leaders are responsive to the needs of the team.

5. Discussion

For engineering educators, two main points of discussion emerge from this study of shared leadership within undergraduate student design teams.

1. **Leadership for undergraduate capstone design teams is a complex phenomenon, encompassing different distributions and amounts across three different leadership forms, which differentially relate to team effectiveness.**

Across the three forms of leadership, this study identified different relationships between decentralization and density with team effectiveness. 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 [28, 29]. The 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 this 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 capstone design teams:**

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

The results show that distributed, vertical 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 regarding a team's extra effort and satisfaction. 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 [14, 27]. An immediate strategy may be to clearly specify team member roles to ensure clear areas of influence for all team members. More importantly, faculty may need to help teams develop strategies to evaluate conflicting influence from within the team and stay focused towards their common goals, which is consistent with the assertions of Muethal and Hoegl [75] and Schaeffner et al. [76] 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 occurs within design teams.

Although a less decentralized 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 more leadership within the design teams may create more engaged team members. Identifying one central leader may artificially truncate the amount of leadership that could occur within the team. Because faculty advisors were included in leadership networks, their leadership may have augmented the leadership of the students. Although distributing leadership had a moderating or negative relationship with measures of team effectiveness, no teams in the study exhibited purely individual leadership, consistent with previous descriptions of the shared, fluid nature of undergraduate engineering team leadership (e.g., [14, 27]). Leadership structures encouraged through team charters of course specific guidance could acknowledge this reality of design team leadership. Parsing leadership between the faculty advisor and the students was beyond the scope of this study. Leadership from a "hands on" faculty advisor and a strong student team leader may be a plausible manifestation of shared leadership within the teams. Further research examining the network centralities of each team member may differentiate faculty and student leadership contributions.

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

Engineering educators may 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 [39]. Rather, TCR leadership, which is based on positive reinforcement and is the most active form within the ME Capstone Full Range of Leadership model, had the most robust relationships with team effectiveness measures, consistent with other meta-analyses [28, 29]. 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 [34]. These leadership behaviors may create a more engaged team overall by shaping the way team members interact as Chi and Huang [77] assert. Although the accountability associated with MEA leadership showed significant relationships when considered separately, consistent with previous transactional leadership findings [7, 39], TCR leadership dominated the parsimonious models for team effectiveness among the leadership behaviors in more complex leadership models.

6. Conclusions

This study suggests that the structure of leadership networks within a capstone design team relates to team effectiveness. The type and amount of leadership that undergraduate mechanical engineering capstone design teams generate and distribute relate to the team members' satisfaction and extra effort. Engineering educators should consider implementing a leadership model for capstone design teams that extends beyond a single team leader approach; however, encompassing every team member equally may not be appropriate. Some vertical structure to the leadership network of the team should be considered. Within the team's leadership network, behaviors consistent with TCR leadership (i.e., positive, inspiring, and showing both compelling vision and purpose) may be most effective. As faculty play a critical role in structuring newly formed capstone design teams, they should consider setting leadership expectations consistent with these findings as they develop course practices and associated content.

7. Future work

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 investigation at the individual team member level is ongoing with the current dataset but is beyond the scope of this article. Additional qualitative research may also provide insights into the complexity of this phenomenon beyond what the available quantitative 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 of 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 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.

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