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Evolution of Leadership Behaviors During Two-Semester Capstone Design Course in Mechanical Engineering

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Abstract

This study explores the changing self-perceptions of leadership abilities among mechanical engineering students during a two-semester senior capstone design course in which large teams worked on industry-sponsored projects. Leadership behaviors were reported by students using the Competing Values Framework which focuses on student behaviors in four orientations: *Collaborate*, *Create*, *Control*, and *Compete*. The results show that there were some significant differences among self-perceptions at the beginning, middle, and end of the class, especially in the *Create*, *Control*, and *Compete* leadership orientations. Differences in self-perception among men and women were more prominent in the *Create* orientation at the beginning of the course with women starting lower but nearly matching men at the end of the course. Implications of this study generate insights into a potential method of assessing leadership development through the length of a course.

Introduction

As universities strive to graduate engineering students who can make an impact on society, engineering leadership programs have become more prominent. The National Academy of Engineering [1] as well as various engineering professional societies highlight the importance of leadership skills in engineering [2-6]. This trend is reinforced by the newly approved ABET Criteria for the 2019-20 review cycle that includes "the ability to function effectively on a team whose members together provide leadership … establish goals, plans tasks, and meet objectives" [7]. With these ABET changes come questions about how to assess leadership. Because the conversation among educators on developing leadership in engineering students is growing, this research seeks to better understand the ways students exhibit leadership behaviors in their group work, how these behaviors could be measured, and strives to answer the question of how engineering students' leadership behaviors evolve during the course of a year-long capstone design course.

Background

In the past ten years, engineering leadership development programs have become more common at schools of engineering across the country [8]. Despite a call for engineering leadership education [2-7], most current engineering leadership development programs exist outside of the formal curriculum [8]. This can lead to engineering students' and faculty's lack of belief in the value of such education, and a general resistance to it [9]. With the updated ABET accreditation requirements [7], engineering programs will be working to determine how to incorporate leadership concepts into their curriculum. Experiences that allow students to develop their skills related to self-awareness, teamwork, project management, team development, and mentoring are essential to building leadership abilities and confidence [10]. These types of skills can also be linked to experiences students have through courses, such as capstone design [11].

The theoretical framework used in this study to explore participant-reported leadership behaviors in the context of working with a team is the Competing Values Framework (CVF). The CVF outlines four different leadership orientations or behaviors: *Collaborate*, *Create*, *Control*, and *Compete* [12]. Figure 1 shows the four roles in quadrant form, highlighting the leader type and theory for effectiveness of each orientation. The CVF is based on the concept of behavioral complexity, the ability of an individual or team to exhibit behaviors aligning with various leadership orientations. An individual who has the ability to leverage various leadership behaviors as needed in given situations is shown to be a more effective leader than an individual who relies on only one set of behaviors, hence the concept of competing values [12, 13]. Therefore, the CVF is not meant to identify a participant in one quadrant or another, but to highlight an individual's tendencies with the goal of continuing to diversify that individual's abilities among all of the quadrants.

Individual level of skill in each of the four quadrants, behavioral complexity, is measured through the use of the Managerial Behavior Instrument (MBI), an empirically tested instrument with evidence of validity that employs a 360-degree assessment methodology in a professional business setting [13]. The MBI has also been used to assess engineering leadership development among students [14] and makers [15]. Research has shown that various behaviors outlined in the MBI, such as *managing processes* and *leading change*, correlated to higher team grades among engineering students [15].

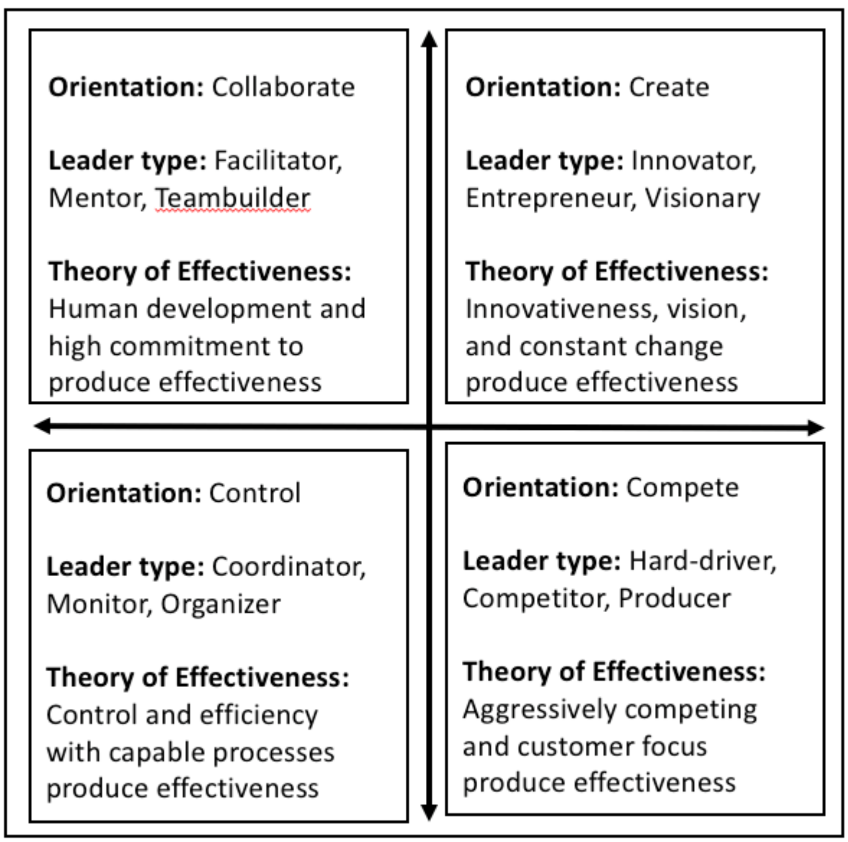


Figure 1. The Competing Values Framework summary [12]

Using the Competing Values Framework (CVF) and accompanying Managerial Behavior Instrument (MBI), this study compares mechanical engineering student self-reported leadership behaviors at the beginning, middle, and end of a year-long capstone design course at a large, public institution. This class setting is used because of its experiential nature, which aligns with the CVF's focus on leadership behaviors.

Research Questions

RQ1. Do senior students participating in a two-semester capstone design course and working in large teams change their self-perceptions of leadership behaviors as defined in the four quadrants of the CVF over time?

RQ2. What are the differences among male and female students in how their self-perceived leadership attributes change over time during a two-semester capstone design experience?

Context

Participants in this study were the students enrolled in a two-semester mechanical engineering capstone design course during the 2016-17 academic year at a large, public university, with Carnegie classification of doctoral-granting with highest research activity. The majority of the student subjects were in their fourth year of their undergraduate studies, with graduation impending upon completion of the course. Teams consisted of seven to nine students each. There were 242 students enrolled in the course and 235 individuals, consisting of 202 men and 33 women, took the pre-assessment survey for a response rate of 97 percent. This percentage changed over time as fewer students took the mid and post-assessments. Project teams were formed through a team matching process undertaken by the instructors. After reviewing the project options, students indicated their top five choices. Based on project-preference, GPA, and other general skills and interests, teams were formed. Team members generally had similar project preferences and complementary skills. Once teams were formed, each team submitted proposals to project sponsors. Project matching was done taking both student and industry sponsor preferences into account.

The capstone design experience under investigation consisted of a team of students working on an industry sponsored project for two semesters from fall to spring. The class was set up as a transitional experience for students, where they have an employee handbook instead of a syllabus, faculty advisors were known as directors, and the industry project sponsors were known as the clients. Industry sponsors paid $16,000 to work with a student team, creating an environment which provides the student teams an authentic responsibility to fulfill their clients' needs. Teammates worked together to decide which of the team members served as the Project Manager, Communications Director, Manufacturing Engineer, Systems Engineer, and other roles, as determined by the project scope. In the course, students filled out periodic peer and self-evaluations, independent of this research, using a peer evaluation survey created for the course. The first peer evaluation was done at the end of the first semester, before the mid-assessment was distributed. Students were able to view their personal peer evaluation report and discuss their performance with their assigned faculty advisor. A final peer evaluation survey was completed near the end of the course, just before the post-assessment survey. The course included one leadership coaching session for the project manager of each team and no additional, intentional leadership development training. The mechanical engineering curriculum up to this point includes a professionalism course and two projects courses, one as a cross-disciplinary first-year experience and one in the third-year. It is likely that some of the students have leadership education by participating in certificates or minors (i.e. leadership certificate, business minor, engineering management minor) or experiences from co-curricular/extracurricular activities but that data is out of the scope of this study.

Methods

The research team administered the series of three leadership surveys during the 2016-17 academic year. These surveys were included with the typical assessment surveys used in the two-semester course. The pre, mid, and post-assessments were administered in mid-September, late January, and early May, respectively.

The survey was derived from the Managerial Behavior Instrument (MBI), based on the theory of the Competing Values Framework (CVF) [13]. The original survey was validated using a sample of employees from the business sector. The research team altered the survey slightly to be appropriate to an engineering education setting. For example, the phrase "insuring that company policies are known" was changed to "insuring that course policies are known" to make sense to engineering students. The 36 items to measure leadership behaviors are Likert-type responses on a scale of 1 to 5 (strongly disagree, disagree, neutral, agree, strongly agree); all items are positively worded [13,16].

The researchers took the student self-reported data for each of the three survey instances and calculated the median student score for each quadrant of the CVF. Because the crux of the theory is determining behavioral complexity, with the value in assessing behaviors that align with multiple quadrants, the resulting scores were from each quadrant individually rather than combining the scores from all 36 items. Once each student had a median score in each quadrant, the researchers used IBM SPSS v. 24 to run a Friedman Test for each quadrant. This test is appropriate for non-parametric data that includes more than two repeated measures of the variable under investigation. This test compared pre, mid, and post-assessment scores and indicated whether there was significant change in each series of assessments. Focusing on the quadrants where there was significant change, the researchers did post-hoc analysis using Wilcoxon Signed Rank Tests to specifically determine whether the change was from pre to mid; mid to post; or pre to post. Additionally, the researchers conducted Mann-Whitney U testing to compare scores from men and women.

Results and Discussion

This section integrates the results, as shown in Figures 2-3 and Tables 1-2, with discussion of these results. Many of the changes among the assessments are significant to varying degrees. Because of variety of student perceptions of self and of what level of skill constitutes an "agree" versus a "strongly agree," the discussion focuses on the relative change over time rather than the nominal values. Because some students did not fill out each of the three surveys, the n values vary from test to test and are shown in the tables.

RQ1. Change over Time

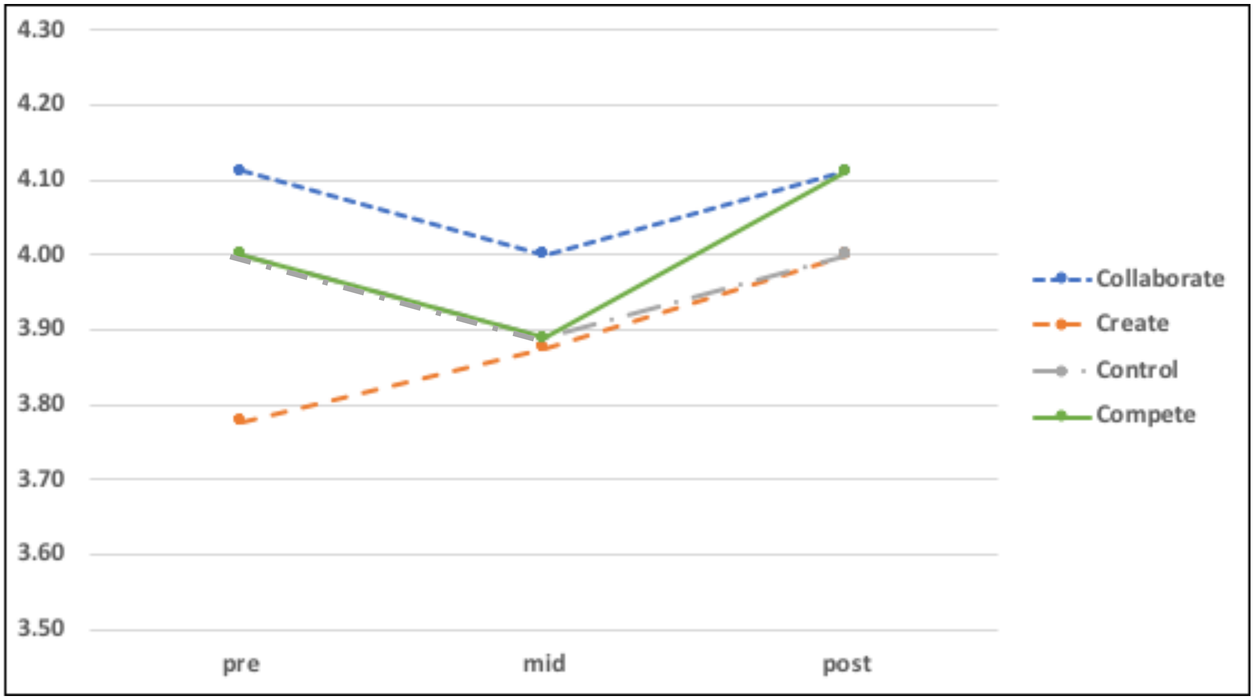
Table 1 shows the results of the statistical analysis of the change in student ratings over time. Using median data, the first analysis completed was the Friedman Test, because of its relevance for non-parametric data with more than two repeated measures. From that test, the researchers learned that there was statistically significant change over time in the *Create*, *Control*, and *Compete* quadrants. A post-hoc analysis, using the Wilcoxon Signed-Rank Test, of these three quadrants showed that there was no significant change from the pre-assessment to the mid-assessment; alternatively, significant change was shown when comparing the mid to the post-assessment.

Table 1. Significant changes in students' leadership behavior scores over time

	Collaborate	Create	Control	Compete
Friedman Test, (n=210)				
p	.414	.000**	.005*	.000**
Pre-Mid (n = 227)				
p		*.595*	*.170*	*.262*
No. students decrease	No significant changes	-	-	-
No. students increase		-	-	-
No. students tied		-	-	-
Mid-Post (n = 210)				
p	-	*.001**	*.001**	*.000***
No. students decrease	-	*32*	*25*	*25*
No. students increase	-	*68*	*; 55*	*60*
No. students tied	-	110	130	125
Pre – Post (n = 214)				
p	-	*.001**	*.021**	*.003**
No. students decrease	-	*32*	*36*	*36*
No. students increase	-	*65*	*55*	*67*
No. students tied	-	117	214	111

* p < 0.05; ** p< 0.001

As shown in Figure 2, students' reported confidence in the quadrant areas decreased from the pre-assessment to the mid-assessment in the *Collaborate*, *Control* and *Compete* quadrants. Additionally, the rate of change in the *Create* quadrant increases over time. Student scores increased for each quadrant from the mid-assessment to the post-assessment. Focusing on the first and final scores, the *Collaborate* and *Control* rankings each started and ended at about the same level, while the *Create* and *Compete* orientation rankings ended at a higher level than they began.



*the *Control* line aligns with the *Compete* line from pre to mid time points

Figure 2. Median score over time for entire sample (range from 1-5, 5="strongly agree."

The apparent decrease between the pre-assessment and mid-assessment scores in three of the orientations could be attributed to the students having overly confident self-perceptions at the beginning of the class, before the hard work had begun (although these decreases were not statistically significant). As shown in Table 2, very few students reported themselves as below "neutral" in even one leadership orientation with very small percentages of students reporting themselves as below "neutral" in two, three, or four quadrants at all the points in time. Because of this, the research highlights the relative change in values rather than exact numerical values.

Table 2. Percent of students with mean scores below "neutral" (3) in one or more quadrants

Assessment Time	1 Quadrant	2 Quadrants	3 Quadrants	4 Quadrants
Pre (n=235)	7.3	0.4	0.4	0
Mid (n=210)	7.5	3.1	0.4	0
Post (n=214)	6.6	1.9	0.5	0

Self-assessments have been shown to be vulnerable to bias based on two broad categories: people do not know what they do not know and people tend to be overly optimistic in neglecting relevant information for an accurate assessment [17]. By midway through the year-long course, however, students had likely landed on a more normalized self-perception, after having months of additional experience, feedback on their performance, and the ability to benchmark themselves against teammates. These methods, shown to be effective at providing improved self-assessment [17], were supplemented by peer assessment through the peer evaluation survey, which each student has opportunity to discuss with their faculty advisor, in a personalized "performance review" session. The peer evaluations includes elements that relate to leadership such as teamwork and communication. Personalized feedback such as this is a proven way to support improved self-assessment, when offered with substantial reassurance of self-worth [17].

As shown in Table 1, the changes from the mid-assessment to post-assessment were significant in the *Create*, *Control* and *Compete* orientations. The change from mid to post was more significant than the change from pre to post in the *Control* and *Compete* quadrants, highlighting that the mid-assessment may have been a more realistic collective self-assessment than the pre-assessment. The students potentially realized some of what they did not know at the beginning of the course and were able to be more accurate in their self-perceptions once they had more experience.

As shown in Figure 2, the *Collaborate* score and the *Compete* score are at a similar level at the time of the post-assessment. While this may seem contradictory, the Competing Values Framework allows for high levels in each area. The *Collaborate* orientation survey questions include “employing participative decision making” and “recognizing feelings” while the *Compete* survey questions include “getting work done quicker in a team” and “modeling intense work effort.” These questions describe different behaviors, but they also are not necessary contradictory or mutually exclusive. As an example, a good team leader could encourage teamwork within the team while acknowledging that some level of competition with other teams can help drive success.

The scores which aligned with the *Control* quadrant, as shown in Figure 2 and Table 1 showed significant change from the mid-assessment to the post-assessment as well as from the pre-assessment to the post-assessment. The *Contro*l orientation focuses on the management of team activities with survey questions such as “keeping projects under control” and “making sure formal guidelines are clear.” In a year-long project, these skills align with project management outcomes typical of capstone courses [11,18,19].

The *Create* scores increased throughout the time of the design course, as shown in Figure 2, which makes sense as students are immersed in a year-long design experience that encourages them to think creatively about a technical problem and to be open to new social techniques in working with clients, faculty advisors, and teammates. Students who thrive in the *Create* orientation are those who are more willing to take risks and think of bigger and bolder solutions. Survey questions that align with the *Create* quadrant are “encouraging teammates to try new things” and “Initiating bold projects.” Significant increases in scores are observed both from the mid-assessment to the post-assessment and from the pre-assessment to the post-assessment (Table 2). The trend in *Create* levels only moved upward during the course of the class, beginning at a point that was lower than the other three quadrants. Before taking the senior capstone design course, students had relatively little opportunity for creativity in coursework beyond a first-year design course and a junior-year structured project. This capstone design course is an opportunity for each project team to be independently creative in solving their unique problem. These results align with desired outcomes (such as conceptual design) already integrated into other capstone design courses [11, 18, 19].

RQ2. Gender Effects

The researchers used the Mann-Whitney U test to compare the sample of men to the sample of women in each of the quadrants at each of the assessment time periods. The only statistically significant difference between the reported scores from men and women was in the *Create* quadrant at the pre-assessment (p=.047). This result needs additional research to become more reliable because of the small sample size of the women student sample, which may skew the results. While it is appropriate to use the Mann-Whitney U test with unequal sample sizes [24], a larger difference in sample sizes may result in a diminished ability to detect a significant difference.

Figure 3 highlights the trends over time of the self-reported leadership orientations in both men and women.

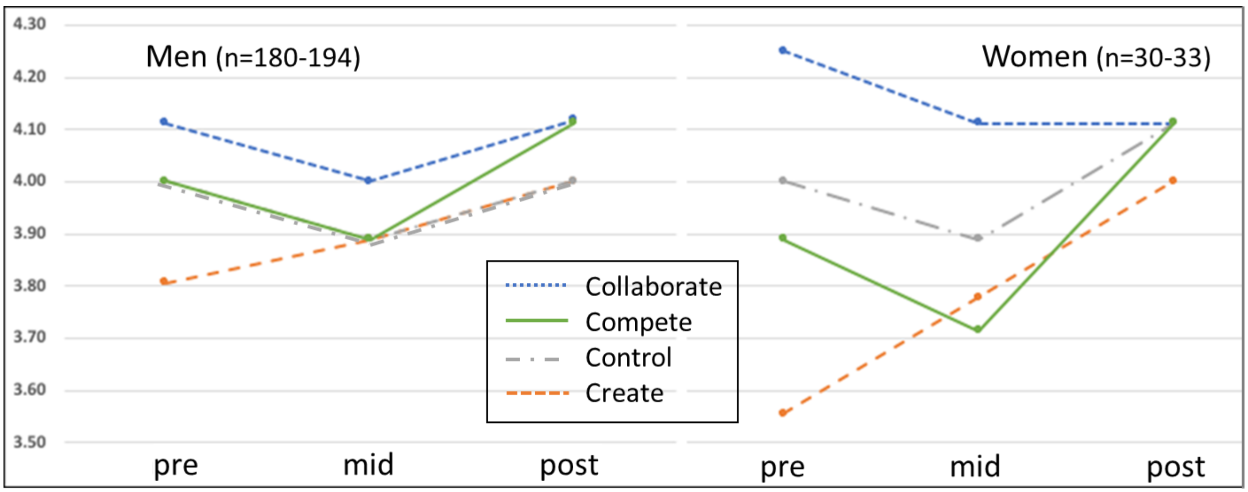


Figure 3. Reported leadership orientation levels for men (left) and women (right)

Because men make up the majority of the students (n=180-194 per assessment), their cumulative data plays a stronger role in influencing the consolidated data described earlier. There were few women in the data set (n=30-33), about 14 percent of the total sample, similar to national figures of 13.8 percent of Bachelor's degrees in mechanical engineering awarded to women [20].

As shown in Figures 3a and 3b, both men and women had a similar trend among orientations with an initial decrease in *Collaborate*, *Control*, and *Compete* scores and a constant increase in the *Create* score. For the women, the downward slopes in the first three orientations are comparable, but the *Compete* slope from the mid-assessment to the post-assessment is much steeper.

In comparing *Collaborate* scores among men and women in Figure 3, the scores of both the men and the women drop from the pre-assessment to the mid-assessment at comparable rates. From the mid-assessment to the post-assessment, however, the rate of change is much different. Women's scores remain constant and men's scores increase to meet the women's scores. The men's score at the end of the course is almost equivalent to the men's score at the beginning of the class. This data indicates the men thought they were good at collaborating, had a reality check mid-course, and then gained their confidence again by the end. Women, however, considered themselves strong at collaborating at the beginning of the course, normalized in the mid-course and stayed there, leaving their final score as lower than where they began. While they lost ground in that area, it can be seen in Figure 3b that women's self-ratings for collaboration are higher than their ratings for the three other orientations. Research shows that students, both men and women, list professionalism traits like collaboration as important outcomes of their capstone experience while women tend to value them more than do men [11]. This may explain how the women's mid-assessment score turned out to be a realistic perception of where they were and the perception remained constant through the end of the study.

As shown in Figure 3, the men in the course ranked themselves higher than did the women on their belief in their ability to *Create*. Both groups increased their scores during the course of the course, but women did so at a much higher rate. The women's scores indicate a low level of confidence in creativity at the beginning of the course. This low-level of self-reported confidence in the ability to create aligns with data that shows that evaluation of creativity is gendered, with even supervisors tending to underestimate women's creativity level. Both men and women tend to stereotype gender in this way [22], aligning with the lower early self-assessment by the female students. By the end of the course, however, the men and women reported similar, higher scores in the *Create* orientation. The capstone experience builds confidence in the *Create* orientation in students.

In the *Control* leadership orientation, the scores for men and women are about the same at the pre and mid-assessments; however, the women's reported scores increase more rapidly during the final semester of the course.

As shown in Figure 3, men and women had a similar rate of decrease in their *Compete* score from the pre-assessment to the mid-assessment, yet women had a stronger increase in their scores on the post-assessment, bringing them to the same level as the men. Psychological research shows that men generally react more strongly than women to the potential for intergroup competitions and dilemmas [22]. These conclusions do not align well with the results of this study, where women reported generally similar trends in their competitive nature to the trends of men. Research in an engineering education setting show that women are interested in joining competition teams, but the nature of the experience ranges based on the level of acknowledgement of the woman's skills by the male team members [23].

Limitations and Future Work

There are various limitations to this study. The results are self-reported prompting the research emphasis to be change over time rather than exact score values. The sample size for the women in the study is much smaller than that of the men, leading to a strong male bias in the aggregate data and difficulty in comparing the two groups to one another. The full sample consists of students from only one institution and one discipline, so broad generalities about engineering students cannot be made. Furthermore, the study subjects are not taking this class in isolation but are taking other classes and experiencing other things during their senior year of college. They socialize, work, and do research, presumably at an increasing level of responsibility since they are upperclassmen. Students in their senior year are also transitioning their mindset to life after college which would be posited to transition their behaviors to become more professional and serious about things like coursework.

In the next phase of the study, the researchers plan to address some of these limitations. In work currently in process, the researchers will supplement self-ratings with peer and instructor ratings of individual performance. The study integrates data from senior exit surveys to understand other curricular and co-curricular activities which likely affect leadership development during college and the senior year in particular. The subjects of this follow-on research are across institutions and disciplines and include a higher percentage of women students in disciplines like environmental engineering. Additional work will also include the behavioral complexity of a team and comparing to team performance as reported by industry members, instructors, and the students themselves.

Conclusion

Results show that some student-reported leadership behaviors changed significantly from the beginning to the end of a year-long capstone design course. In the *Collaborate*, *Control*, and *Compete* orientations, perceived levels of abilities decreased from the pre-assessment to the mid-assessment, indicating a level of overconfidence in students at the beginning of the course. A more accurate assessment of student improvement may be to focus on the mid-assessment as a more realistic point to assess student ability. In the *Create* orientation, both men and women showed improved confidence throughout the course, with women improving more drastically, aligning with other research on creativity and gender norms. The leadership orientations with the most significant levels of change were the *Create*, *Control* and *Compete* orientations, highlighting the value of the capstone experience in rounding out the students' abilities to lead from multiple orientations.

References

[1] NAE, "Engineer of 2020," National Academy of Engineers.

[2] American Academy of Environmental Engineers, "Environmental engineering body of knowledge 2009," 2009.

[3] American Institute of Chemical Engineers, "Body of Knowledge for Chemical Engineers," 2015.

[4] American Society of Civil Engineers, "Civil engineering body of knowledge for the 21st century: Preparing the civil engineer for the future, 2nd Ed.," 2008.

[5] American Society of Mechanical Engineers, "Vision 2030: Creating the future of mechanical engineering education," 2011.

[6] National Society of Professional Engineers, "Professional engineering body of knowledge, First Edition," 2013.

[7] ABET, "Criteria for Accrediting Engineering Programs." Retrieved January 28, 2018 from http://www.abet.org/wp-content/uploads/2017/12/E001-18-19-EAC-Criteria-11-29-17-FINAL_updated1218.pdf, 2017

[8] R. Graham, "Educating tomorrow's engineering leaders: What do we really mean by 'engineering leadership', how can it be developed and nurtured?," *Materials Today*, vol. 12, no. 9, p. 6, Sep. 2009.

[9] C. Rottman, R. Sacks, and D. Reeve, "Engineering leadership: Grounding leadership theory in engineers' professional identities," *Leadership*, vol. 11, no. 3, pp. 351–373, 2015.

[10] G. Warnick, J. Schmidt, and A. Bowden, "An experiential learning approach to develop leadership competencies in engineering and technology students," presented at the ASEE Annual Conference and Exposition, Indianapolis, 2014.

[11] O. Pierrakos, M. Borrego, and J. Lo, "Assessing learning outcomes of senior mechanical engineers in a capstone design experience," in *American Society for Engineering Education Annual Conference & Exposition*, Honolulu, HI, 2007.

[12] K. S. Cameron, R. E. Quinn, J. DeGraff, and A. V. Thakor, *Competing Values Leadership*, 2nd ed. Northampton, MA: Edward Elgar Publishing, Inc., 2014.

[13] K. A. Lawrence, P. Lenk, and R. E. Quinn, "Behavioral complexity in leadership: The psychometric properties of a new instrument to measure behavioral repertoire," *Leadership Quarterly*, vol. 20, pp. 87–102, 2009.

[14] C. R. Zafft, S. G. Adams, and G. S. Matkin, "Measuring leadership in self-managed teams using the competing values framework," *Journal of Engineering Education*, pp. 273–282, Jul. 2009.

[15] J. L. Oplinger, M. Lande, and S. S. Jordan, "Leadership characteristics within the Making Community," in *ASEE Annual Conference and Exposition*, Seattle, WA, 2015.

[16] Blinded author and publication

[17] D. Dunning, C. Heath, and J. M. Suls, "Flawed self-assessment: Implications for health, education, and the workplace," *Psychological Science in the Public Interest*, vol. 5, no. 2, pp. 69–106, 2004.

[18] A. Hurst and O. G. Nespoli, "Student perceptions of value of peer and instructor feedback in capstone design review meetings," presented at the Capstone Design Conference, Columbus, OH, 2016.

[19] J. McCormack *et al.*, "Assessing professional skill development in capstone design courses," *International Journal of Engineering Education*, vol. 27, no. 6, pp. 1308–1323, 2011.

[20] B.L. Yoder, 2016, Engineering By the Numbers 2016, in Engineering College Profiles and Statistics; American Society for Engineering Education.

[21] D. Proudfoot, A. C. Kay, and C. Z. Koval, “A gender bias in the attribution of creativity: Archival and experimental evidence for the perceived association between masculinity and creative thinking,” *Psychological Science*, pp. 1–11, 2015.

[22] M. Van Vugt, D. De Cremer, and D. Janssen, “Gender differences in cooperation and competition: The male-warrior hypothesis,” *Psychological Science*, vol. 18, no. 1, pp. 19–23, 2007.

[23] C. E. Foor, “‘We weren’t intentionally excluding them...Just old habits:’ Women (lack of) interest and an engineering student competition team,” presented at the ASEE/IEEE Frontiers in Education Conference, Oklahoma City, OK, 2013.

[24] H.B. Mann, D.R. Whitney “On a test of whether one of two random variables is stochastically larger than the other,” Annals of Mathematical Statistics, vol 18, no. 1, pp. 50-60, 1947