Assessing the Impact of University-Industry collaborative Lean Six Sigma Capstone Projects on Engineering Management Students

Dr. Hilda Cecilia Martinez Leon, Clarkson University

Hilda Cecilia Martinez Leon received the B.S. degree in industrial engineering, the M.S. degree in manufacturing systems, and the D.Sc. degree in engineering sciences from Monterrey Tech, Mexico. She also received the Ph.D. in systems and engineering management from Texas Tech University, Lubbock. She is also a Lean Six Sigma Master Black Belt. Her work experience is related to the product lifecycle management and manufacturing processes from the electronic and automobile industry when she was with Honeywell, Siemens VDO Guadalajara, and Cummins, Inc. She has worked as a consultant in Lean Six Sigma across industry sectors, more recently in Healthcare, where she has coached students and industry employees to get their lean six sigma green belt certification. She is currently an Assistant Professor in Engineering and Management at the David D. Reh School of Business at Clarkson University, Potsdam, NY, where she teaches Quality Management and Lean Enterprise, Engineering Design Capstone courses, Operations and Supply Chain Management-related courses. Her research interests include lean product development, six sigma, project management, systems engineering, and applied statistics. Dr. Martínez is a member of the Institute of Industrial Engineering and the Systems and Engineering Management Society.

Dr. Michelle Crimi, Clarkson University

Dr. Michelle Crimi is the David Spatz '68 Endowed Chair for the Director of Engineering & Management Program at Clarkson University.

Assessing the Impact of Lean Six Sigma Capstone Projects on Engineering Management Students

Abstract

Capstone design projects are meant to provide an invaluable learning experience to senior students. However, the project experience can be disappointing if students are not provided with challenging projects and lack the guidance of a rigorous problem-solving approach. To overcome this problem, we have developed a collaborative approach to enhancing the learning experience for engineering management (or industrial engineering) capstone design courses. The core of this approach is problem-based learning through the execution of lean six sigma (LSS) projects implemented via university-industry partnerships. The ultimate goal of this approach is to facilitate the integration and application of theoretical knowledge while promoting the development of professional skills in undergraduate students as demanded by business organizations. The purpose of this paper is to assess the extent to which our pedagogical infrastructure for a completely hands-on experience in capstone design courses has on students during their transition to the workforce and early careers. Student surveys were conducted to quantify the impact of semester-long projects. Student responses from the LSS and non-LSS capstone courses were analyzed. Our findings show that collaborative LSS capstone projects help students gain a better understanding of how to apply the theory to practical situations while preparing them to approach and solve problems in real-world settings confidently. We also found that the LSS green belt certification helped recent graduates to transition to the workforce more easily, gain more credibility among co-workers and supervisors and make contributions quicker than other new hires, get the job they wanted faster, and overall advance in their careers.

Introduction

An engineering capstone design project is meant to be the culminating achievement of graduating senior undergraduate students as they demonstrate their competency of designing economically feasible solutions to complex and interdisciplinary problems [1]. As such, capstone projects are meant to provide real-world experience with a clear objective for solving a practical problem where a team of students use their engineering knowledge and use their skills

to solve an unstructured problem [2]. However, the project experience can be disappointing, and an invaluable learning opportunity undermined if students are not provided with challenging projects and lack the guidance of a rigorous problem-solving approach. As [1] found in their study, the optimal capstone experience is highly dependent on the student preparation, project selection, and instructor mentorship. From these three aspects, it appears that the project is the one that drives how students should be prepared and thus influences the mentorship needed from instructors.

Not surprisingly, capstone design course instructors continuously face the challenge of identifying the appropriate type of project. The ideal capstone project is the one that not only covers the course learning outcomes but also exposes students to real-world problems where they can implement and test the effectiveness of their solutions. Thereby, industry-led and -sponsored projects have typically been identified as an approach to addressing this challenge [2]. Likewise, the use of lean six sigma (LSS) has also been used as a problem-solving methodology approach for capstone projects (e.g., [3]). The problem is that this combination is rarely a viable option [2]. Weinstein et al. [4] emphasized that completing LSS projects in an academic semester is extremely difficult.

Moreover, aligning the industry partner schedule to the academic semester is also challenging. To overcome this problem, we have developed a collaborative approach to enhancing the learning experience for engineering management (or industrial engineering) capstone design courses dubbed as EAG^{2}ER (see [5]). The ultimate goals of this pedagogical approach are to make LSS a viable option for one-semester capstone courses and to facilitate the integration and application of theoretical knowledge while promoting the development of professional skills in undergraduate students as demanded by business organizations.

After piloting our approach, and based on our direct observations and student feedback, EAG^{2}ER has proved useful for replicating the work conditions to which students will be exposed after graduation and balancing the theoretical, foundational knowledge with hands-on, real-world experiences. The purpose of this paper is to assess the extent to which our pedagogical infrastructure for a completely hands-on experience in capstone design courses has on students

during their transition to the workforce and early careers. To this aim, we collected feedback in a post-graduation survey to quantify the impact of semester-long capstone projects that had students work on either LSS projects or non-LSS projects but still oriented to solve real-world problems or develop business and technical solutions. It is important to mention here that students who work on a LSS project had the opportunity to take the online Green Belt (GB) training and use their capstone project towards their LSS GB certification. The certification requirements include the completion of the training modules, the successful completion of a project, and a passing grade of the certification exam.

Accordingly, we organized this paper as follows. First, we present an overview of our pedagogical approach dubbed as EAG^{2}ER. Then, we present the research methodology used to collect student responses from the LSS and non-LSS capstone courses. Next, we present our results and discuss our findings.

Overview of EAG^{2}ER

The proposed pedagogical approach is based on university-industry collaborations that provide the project infrastructure for successful LSS projects. Thereby, EAG^{2}ER starts with the exploration of potential industry-university collaborations and ends with the recognition of the success achieved by both students and staff involved in the project. EAG^{2}ER stands for Explore (potential collaboration), Agree (to collaborate), recognize Gaps, Get started, Execute (the project), and Realize and Reward (project achievements.) Figure 1 presents the EAG^{2}ER roadmap in a swimlane diagram and identifies the responsible actor for each step.

The swimlane process map shown in Figure 1 depicts the interacting parties involved in the collaborative effort. The first three stages of the framework take place before starting the academic semester. Notice that project identification is the output of the recognize gaps (G) stage. Once the project (or problem) is identified, the team members should be selected. It is important to note here that projects are intentionally selected at the "green-belt" level as students may use their capstone project to fulfill one of the requirements for the third-party LSS GB professional certification program. The focus of "green-belt" project is on solving a local problem in an existing process for which process performance data is collected and analyzed to

pinpoint the root cause of the problem. Solutions are designed and new protocols implemented to improve the process. The operational improvement is translated into annual savings that range between 10-50K USD. Getting started (G) should end with the kick-off meeting during the first week of classes. In this meeting, students and industry team members meet and start sharing their perspectives on the problematic situation. The Execute (E) stage is an interactive stage where the four key aspects of a successful capstone experience are actively interacting: project, student contributions, interactions with industry team members, and instructor mentorship. During the final exam week, the recognition (R) stage takes place where students present their tangible results to the industry partner's leadership team, faculty, and student peers. It is also in this stage where students, who completed their project successfully, have the option of taking the LSS GB certification exam offered by a third-party professional certification program. The LSS GB certification program chosen is accredited by the International Association for Six Sigma Certification, the International Association for Continuing Education and Training, and the American National Standards Institute. For more details on this framework, please refer to [5].

Research Methodology

The goal of this research is to quantify the effectiveness of EAG^{2}ER beyond the 100% certification rate of our students. That is, the interest is in assessing the extent to which the proposed pedagogical approach, EAG^{2}ER, used in the engineering & management (E&M) capstone course better prepares students for work environments that call for problem-solving, multidisciplinary collaboration, disciplined management, effective project execution, and data-driven decision-making. To this aim, a 28-question, Likert scale survey was designed. Questions were grouped into categories to assess their level of learning, critical thinking, student engagement as well as the impact of the project execution and professional certification, project mentoring on their development of professional skills and employability. Questions were based on previous works that have assessed the impact of pedagogical approaches on students (e.g., [1], [6]–[9].

The questions in the learning category focused on identifying and measuring the perceived level of importance of their capstone experience when learning new material, retaining more, and applying E&M concepts to a real-world problem. In particular, we were interested in assessing the extent to which the capstone project helped them to understand better how to apply

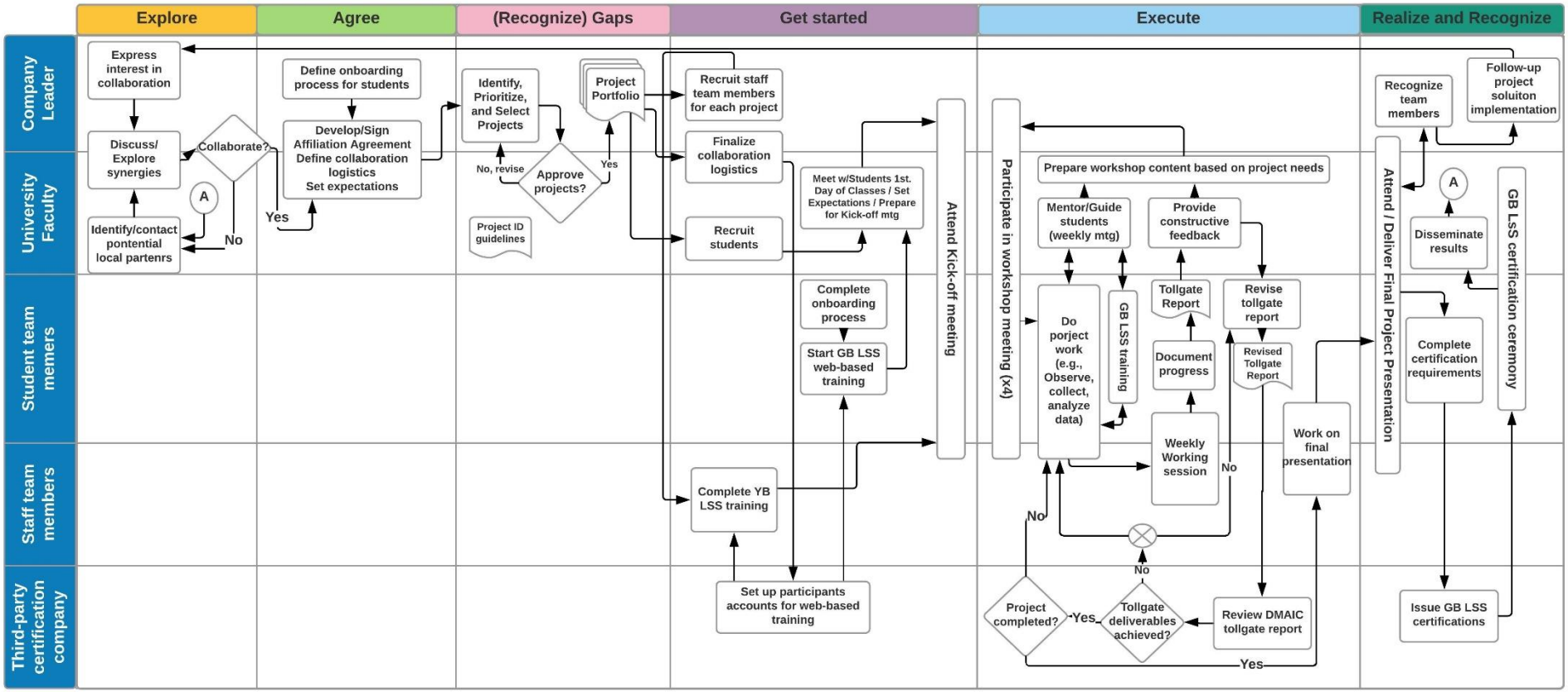

Figure 1. EAG^{2}ER Roadmap

theoretical concepts or models to real-world situations. Meanwhile, in the critical thinking category, we were interested in assessing the degree to which their projects were thought-provoking in such a way that allowed them to analyze the problem from multiple perspectives. The questions related to student engagement were based on the assumption that students are more likely to be engaged when their capstone projects as these are more realistic, and thus students find them more appealing, challenging, and interesting. The instructor mentorship greatly influences the quality of the project execution as well as the interactions students had with the industry-partner team members and the student's learning on how to overcome roadblocks. Thus, questions under the project execution construct were intended to identify the main struggles student teams faced and the value of instructor mentorship as well as instructional sessions. In regards to professional (or "soft") skills, we were interested in understanding the benefits the LSS capstone project had on recent graduates. For instance, if the project experience helped them to enhance their creativity, communication and, teamwork skills. Likewise, we were also interested in assessing the extent to which the LSS green belt certification has contributed to their professional development.

The questions used a five-Likert scale that ranged from strongly agree to strongly disagree. The survey was a one-time activity and targeted E&M alumni that took the enhanced E&M capstone with LSS (18 responses or 100% response rate) in the Spring 2017 and 2018 *and* E&M students that did not take the enhanced version of the E&M capstone design course (23 respondents or 16.4% response rate) between 2013 and 2018. Participants were surveyed to assess their perception of job preparedness for work, easiness on job placement, and career development. The overall study had a response rate of 25%.

Results

The analysis we present here consists on the tabular percentage responses from both types of courses, the enhanced version with lean six sigma (shown as LSS) and the traditional capstone course (shown as other). LSS projects were focused on improving healthcare support processes whereas non-LSS were focused on more diversified areas such as transportation, software development, and product design. A full description of the LSS and non-LSS projects completed is beyond the scope of this paper; however, Table 1 presents some examples of the capstone projects.

Table 1. Capstone Project Examples

LSS projects	Non-LSS projects
Reduction in the average time and variability for: • Inter-hospital patient transfers • Emergency department (ED) and Intense Care Unit (ICU) patient transfers • Pre-operative process for total joint replacements • Orthopedic clinic patient visits • Patient registration process at a community clinic • Preparing and delivering patient food	• Design of a house in a box for humanitarian aid • Redesign of a truck shelving interface • Development of a linear programming model to enhance the capacity planning system in a manufacturing company • Design of an advertising system for commercial vehicles

One of the distinctive characteristics of the capstone LSS projects is that these projects are executed in collaboration with local hospitals' staff and stakeholders. On the one hand, students become hospital interns and have access to both hospital facilities and data. On the other, hospitals' leaders assign multidisciplinary staff members to work with students on a particular project and regard this collaborative effort as a professional development opportunity. As outlined in Figure 1, the structure of the execute (E) phase consisted of 4 four-hour workshops scheduled every three or four weeks at the university, weekly mentoring meetings with students, weekly working sessions with hospital staff, and on-site work such as process observations, data collection, and analysis. Hospital staff members were committed to the project as they had to present project progress along with students during the monthly workshops to the hospitals' leadership teams.

Regarding time commitment, we looked at the student logbooks where they report the number of hours worked on their projects all semester long. For LSS projects, students have reported an average time of 159 hours with a standard deviation of 22 hours. For non-LSS projects, students' logs reported a mean value of 144 hours and standard deviation of 10 hours. It is important to note that the hours logged by LLS students also include the time spent on the online GB training, which students had to take while working on their projects. The online training itself can partially explain the large variability as they could have spent more time on completing the modules or training exercises. However, the time variability can also be attributed to the complexity of the process under study, as students had to spend more time at the hospital trying to understand the problematic situation. Students also had to meet multiple times with hospital

staff, and train and talk to hospitals' staff to get the buy-in for implementing their solution to the problem assigned.

Table 2 presents the questions in sections, one for each construct evaluated: learning, critical thinking, engagement, instructor mentoring, professional skills, and employability. The learning section included six questions. Inspection of Table 2 reveals that the respondents that took the LSS capstone design course (hereafter LSS students) showed agreement (or strong agreement) in all survey questions, not only in the learning section. Whereas the respondents from the traditional capstone design course (hereafter "other" students) show partial agreement that resulted from some neutral and disagreement responses. Between 95% and 100% of the LSS students agree or strongly agree in that their LSS capstone project was relevant and applicable to their field of study whereas 4% and 8% of the non-LSS students disagree on this respectively. The LSS projects took place in local hospitals of upstate New York. Interestingly enough, 14% of the non-LSS students felt that their capstone project did not help them better understand how to apply theoretical knowledge to a real-world situation. Moreover, 100% of the LSS students agreed or strongly agreed that their project provides a helpful mechanism for retaining more of the main topic of their project and that the learning experience was optimal, whereas between 5% and 10% of the non-LSS students disagreed with this statement.

Table 1. Percent responses for capstone courses

Question	Group	SD	D	N	A	SA
Learning						
I felt the use of the capstone project was relevant to my learning of E&M concepts.	LSS	0%	0%	6%	6%	89%
	Other	0%	4%	0%	56%	40%
I felt that what I learned in my capstone project was applicable to my field of study.	LSS	0%	0%	0%	17%	83%
	Other	0%	8%	0%	64%	28%
My capstone project helped me to retain more of the main topic of my project.	LSS	0%	0%	0%	28%	72%
	Other	0%	5%	0%	79%	16%
I felt my capstone project was an optimal learning experience.	LSS	0%	0%	0%	29%	71%
	Other	0%	10%	0%	75%	15%
I felt my capstone project helped me understand better how to apply theoretical models or concepts to real-world situations.	LSS	0%	0%	0%	28%	72%
	Other	0%	14%	0%	55%	32%
I was able to apply E&M concepts and theories as a result of working on my capstone project.	LSS	0%	0%	0%	40%	60%
	Other	0%	4%	0%	83%	13%

(continued on next page)

Question	Group	SD	D	N	A	SA
Critical Thinking						
My capstone project allowed for a deeper understanding of E&M concepts.	LSS	0%	0%	0%	33%	67%
	Other	0%	15%	0%	60%	25%
My capstone project brought together material I had learned in several other E&M courses.	LSS	0%	0%	0%	38%	63%
	Other	0%	0%	0%	68%	32%
My capstone project helped me become a more data-driven thinker.	LSS	0%	0%	0%	29%	71%
	Other	5%	30%	0%	60%	5%
My capstone project helped me to become a better problem-solver.	LSS	0%	0%	0%	22%	78%
	Other	0%	8%	0%	54%	38%
My capstone project allowed me to view an issue from multiple perspectives.	LSS	0%	0%	0%	24%	76%
	Other	0%	8%	0%	54%	38%
I thought the use of the semester project was thought-provoking.	LSS	0%	0%	0%	33%	67%
	Other	0%	7%	0%	54%	39%
Engagement						
I was more engaged in class when discussing my capstone project.	LSS	0%	0%	11%	33%	56%
	Other	0%	4%	24%	52%	20%
My capstone project was more entertaining than educational.	LSS	17%	78%	6%	0%	0%
	Other	8%	52%	28%	12%	0%
I felt more immersed in my capstone course than other courses.	LSS	0%	0%	6%	17%	78%
	Other	4%	8%	16%	48%	24%
I took a more active role in the learning process with my capstone project than with any other course activity outside the project.	LSS	0%	0%	11%	50%	39%
	Other	0%	4%	60%	32%	4%
I felt my capstone course was more challenging than other engineering courses.	LSS	0%	6%	33%	44%	17%
	Other	4%	42%	38%	13%	4%
My capstone project added a lot of realism to the course.	LSS	0%	0%	0%	18%	82%
	Other	0%	4%	4%	50%	42%
Instructor Mentoring						
I felt team meetings with the instructor (or workshops) were better than class sessions.	LSS	0%	0%	0%	28%	72%
	Other	5%	0%	0%	60%	35%
I felt socially engaged with my instructor to receive feedback on my project.	LSS	0%	0%	0%	33%	67%
	Other	8%	4%	4%	56%	28%
Professional Skills						
I felt my capstone project helped me improve my oral communication skills.	LSS	0%	6%	0%	53%	41%
	Other	0%	16%	0%	68%	16%
I felt my capstone project experience helped me to become more resilient (e.g., being able to handle day to day issues that arise, overcome obstacles, etc.)	LSS	0%	6%	0%	50%	44%
	Other	0%	0%	0%	75%	25%

(continued on next page)

Question	Group	SD	D	N	A	SA
I felt my capstone project experience has helped me become a better leader/project manager.	LSS	0%	0%	0%	53%	47%
	Other	5%	11%	0%	79%	5%
I felt that the execution of my capstone project was inefficient (e.g., I wasted my time, money, made slow progress, had to learn the hard way, was not on track, etc.)	LSS	35%	59%	6%	0%	0%
	Other	8%	52%	28%	8%	4%
Employability						
I felt my capstone project helped me get the job I wanted.	LSS	0%	19%	0%	31%	50%
	Other	36%	45%	0%	18%	0%
I felt my capstone project helped me discern what area I wanted to work in after graduation.	LSS	0%	13%	0%	31%	56%
	Other	23%	23%	0%	54%	0%
I feel my capstone project experience has helped me advance in my career.	LSS	0%	6%	0%	47%	47%
	Other	27%	20%	0%	53%	0%
I felt my capstone project experience helped me do better at job interviews.	LSS	0%	12%	0%	41%	47%
	Other	11%	22%	0%	56%	11%

A similar pattern is observed in the percentage responses of the six questions comprised in the critical-thinking section. There was a general or strong agreement among all LSS students in their perception of the capstone project being a useful instrument for gaining a deeper understanding of E&M concepts and applying those concepts to the particular contexts of their respective projects. This in turn not only helped them to analyze the problem from multiple perspectives, but LSS helped them to become more data-driven problem-solvers as the overall project was thought-provoking. Conversely, students who worked on a non-LSS capstone project had the greatest disagreement of 35% on the project not helping them to become more data-driven thinkers, followed by a 15% of disagreement on the project not being helpful on knowing how to apply theoretical concepts to a real-world situation, and 8% of disagreement on the project not being helpful for analyzing situations from multiple-perspectives and thus there was this perception of not becoming better problem-solvers. Last, there was a 7% of disagreement among non-LSS students on their project being as thought-provoking.

Student engagement significantly affects their overall learning experience. Also, and while the type of project may influence their engagement, it highly depends on the intrinsic motivation and self-interests of students. At Clarkson University, students get to choose the capstone course section (and thus their types of projects), and in the particular case of the LSS-based capstone

course, students work on the problematic area of their choice. As such, the level of student engagement could be partially explained by the extent to which the student interests are aligned to the project objectives. In spite of having students select the capstone course section of their preference, we observed a more varied pattern in the percentage responses of the six questions asked in the engagement section. 89% of the LSS students strongly agree or simply agree on being more engaged in class when discussing the project whereas 11% had a neutral position. 24% of the non-LSS students, on the other hand, had a neutral position and 4% disagreed with this statement. 94% of the LSS students strongly or simply disagreed with their project being more entertaining than educational. Whereas 12% of the non-LSS students agreed with this statement and 28% had a neutral position. Not surprisingly, 94% of the LSS students felt immersed with their projects whereas 12% of the non-LSS did not, and 16% of them neither agree nor disagree. Interestingly enough, 60% of the non-LSS students reported a neutral position of taking a more active role in their learning with their capstone project than with any other academic project and 46% did not consider their capstone project as more challenging than other engineering projects. In contrast, 89% of the LSS students considered they adopted a more active role in their learning process with their capstone project and only 6% considered their capstone project as less challenging than their other engineering projects. Last, among the LSS student population, there was a general agreement that their project added realism to the course and 8% of the non-LSS students thought the opposite or were neutral.

The success of a capstone project lies in its execution, where project mentoring and constructive feedback play a critical role in guiding students in their thought process for problem-solving. In the instructor mentoring section, LSS students agreed or strongly agreed in its entirety that the meetings with the instructor to discuss their project and tools that could be used in the project were more helpful than the conventional class sessions, and as a consequence felt socially connected with the instructor. However, 5% of the non-LSS students disagreed with this, and 12% of them did not feel socially connected with their instructor.

The last two sections of the survey were intended to assess the benefits of their capstone projects in the early stages of their careers. Interestingly enough, it is in these two sections related to the professional skills and employability where we observe the most disagreement in students'

responses. While the disagreement is more notorious in non-LSS students, there is still some degree of disagreement in LSS students.

The four questions in the professional skills section were intended to assess the level to which the capstone projects promoted the development of these "soft" skills in students. While there is not a clear definition of what a "professional" skill set entails, in the literature, it is often related to effective communication, teamwork, resilience, time management, and conflict resolution, among others [4], [10], [11]. All LSS students reported that their capstone project helped them to become a better leader or project manager and, only 6% did not think that their capstone projects contributed to the development of their communication skills. There was more disagreement in these two aspects among the non-LSS student population with 11% and 16%, respectively. Generally speaking, students felt that their capstone project helped them to become more resilient with only 6% of the LSS students disagreeing with this. The last question in this section reflects their perception of the overall execution of the project which is highly dependent on how they approached and dealt with the changing challenges as the project unfolded. 94% of the LSS students did not think that the way their capstone project was executed was inefficient whereas only 60% of the non-LSS concurred.

Regarding employability, 81% of LSS students agree or strongly agreed with their capstone project experience helping get the job they wanted. As for non-LSS students, only 18% agreed with this statement. 87% of the LSS students also considered their project capstone experience helped them discern the field area they wanted to work in after graduation. This was the case for 54% of non-LSS students. A similar pattern is observed with the capstone project experience as a contributing factor in the advancement of their early careers, with 94% and 53% for LSS- students and non-LSS students respectively. Last, and regardless of the type of capstone project, where the majority of the students, 88% and 67% for LSS- and non-LSS students respectively, reported that their capstone project experience helped them do better in their job interviews.

Conclusions

Overall, and based on the survey responses, the LSS capstone projects framed with the industry-university collaborative approach (EAG^2ER) is perceived by students as a valuable and optimal

learning experience. Survey results suggested that they not only deepened their understanding of E&M concepts but also identified how these fundamental concepts could be applied to real-world situations and they applied it to solve the problem of their capstone projects. Aligned with this, students also described their LSS project as thought-provoking. But most importantly, students reported that their LSS projects helped them to become more data-driven thinkers and in general better problem-solvers not only in the technical aspects of the problem but in the managerial aspects of it as they also improved their communication skills, learned to overcome roadblocks, and manage their time to complete a green belt six sigma project in fourteen weeks, which in turn resulted in a 100% certification rate. Since they witnessed the application of their learning in a project from inception to implementation, they were less likely to view LSS tools as a set of isolated tools. As reported in [5], some of the benefits of earning the LSS GB certification in the senior year were the following: getting the job they wanted faster, a smoother transition to the workforce, gaining more credibility among co-workers and supervisors, and making contributions quicker than other new hires, among others.

It is also worth noting that students who worked on their LSS capstone projects were involved from definition to implementation of the solution. This provided the dynamism and realism of their theoretical knowledge, leading to better-equipped graduates. The semester-long projects, although challenging, offered an opportunity for a high-quality and collaborative learning experience. Overall, we observed growth in students' self-confidence, theoretical and practical knowledge, and level of comfort during job interviews. This, in turn, led students to be better prepared for transitioning to the workforce, and once there, gaining credibility among their co-workers and supervisors and making contributions to their jobs quicker than other new hires.

References

[1] J. A. Marin, J. E. Armstrong Jr., and J. L. Kays, "Elements of an Optimal Capstone Design Experience," *Journal of Engineering Education*, vol. 88, no. 1, pp. 19–22, Jan. 1999.

[2] C. M. Borror, R. L. Berger, S. LaFond, and M. Stull, "Undergraduate Statistics Curriculum: A Large, Unstructured, Complex Problem," *Qual. Eng.*, vol. 24, no. 2, pp. 201–214, Apr. 2012.

[3] D. Kanigolla, E. A. Cudney, S. M. Corns, and V. A. Samaranayake, “Enhancing engineering education using project-based learning for Lean and Six Sigma,” *International Journal of Lean Six Sigma*, vol. 5, no. 1, pp. 45–61, 2014.

[4] L. B. Weinstein, J. Petrick, J. Castellano, and R. J. Vokurka, “Integrating Six Sigma Concepts in an MBA Quality Management Class,” *Journal of Education for Business*, vol. 83, no. 4, pp. 233–238, Mar. 2008.

[5] Martinez Leon, H.C., “Bridging Theory and Practice with Lean Six Sigma Capstone Design Projects,” *Quality Assurance in Education*, vol. 2, no., 1, pp. 41-55, 2019.

[6] E. Cudney and D. Kanigolla, “Measuring the Impact of Project-Based Learning in Six Sigma Education,” *Journal of Enterprise Transformation*, vol. 4, no. 3, pp. 272–288, Jul. 2014.

[7] C. Laux, M. Johnson, and P. Cada, “Project barriers to Green Belts through critical success factors,” *International Journal of Lean Six Sigma*, vol. 6, no. 2, pp. 138–160, 2015.

[8] Y. Liu, “Renovation of a mechanical engineering senior design class to an industry-tied and team-oriented course,” *Eur. J. Eng. Educ.*, vol. 42, no. 6, pp. 800–811, Nov. 2017.

[9] E. J. H. Spelt, P. A. Luning, M. A. J. S. van Boekel, and M. Mulder, “A multidimensional approach to examine student interdisciplinary learning in science and engineering in higher education,” *Eur. J. Eng. Educ.*, vol. 42, no. 6, pp. 761–774, Nov. 2017.

[10] C. M. Anderson-Cook *et al.*, “Statistical Engineering—Forming the Foundations,” *Qual. Eng.*, vol. 24, no. 2, pp. 110–132, Apr. 2012.

[11] National Academy of Engineers, *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press, 2004.