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Bridging theory and practice with Lean Six Sigma capstone design projects

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Abstract

Purpose – The purpose of this paper is to gain a better understanding of the challenges academics face today in developing a knowledge-based economy. In response to these challenges, the authors developed a collaborative approach to enhancing the learning experience for engineering management (or industrial engineering) capstone design courses. The core of this approach is the 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.

Design/methodology/approach – The framework is firmly grounded in theory and methods from project management and quality management, and LSS literature and was tested in an engineering and management capstone design course at the author's university. The case study presented here offers a detailed analysis of the design and implementation of the proposed framework. The authors also present the results of a survey conducted to assess the extent to which the proposed approach contributes to bridging the gap between theory and practice.

Findings – Results from the pilot implementation and survey results revealed that students who took the enhanced LSS capstone course felt that their projects helped them gain a better understanding on how to apply the theory to practical situations while preparing them to approach and solve problems in real-world settings confidentially. The authors also found that the LSS green belt certification helped recent graduates to transition to the workforce more easily, gain more credibility among coworkers and supervisors and make contributions quicker than other new hires, get the job they wanted faster and overall advance in their careers.

Originality/value – The framework is a composition of best practices used in a variety of universities and industries. While the majority of the LSS university-based programs are typically offered at the graduate level and with limited (support for) project executions, the framework proposed here provides the infrastructure for solid company staff-student team collaborations on projects executed from inception to implementation.

Keywords Lean Six Sigma, Pedagogy, higher education, Certification, University-industry partnerships

Paper type Research paper

Introduction

In an environment characterized by rising higher education costs and declining operational budgets, pressure is put on attracting and retaining students through academic programs (Lu *et al.*, 2017). Focusing on merely attracting students, however, is neglecting the critical role universities play in developing a knowledge-based economy (Langstrand *et al.*, 2015), which can be achieved by instilling in students the technical knowledge and developing the skill sets organizations need (Borror *et al.*, 2012; Langstrand *et al.*, 2015).

Employers typically point out that college graduates are technically well-trained and possess detailed expertise in their fields of study; however, they still need to understand

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better how to integrate and use theoretical concepts for improving daily operational practices (Anderson-Cook *et al.*, 2005). Students still need to understand the dynamic challenges and struggles that professionals encounter in organizational settings which are not grasped by the use of supplementary cases (Weinstein *et al.*, 2008). Kanigolla *et al.* (2014) identified that students get limited opportunities to enhance their knowledge in the application of theoretical principles if they are not exposed to project-based learning (PBL). Likewise, Mitra (2004) asserted that academic institutions should ensure that students have an appropriate foundation for knowing not only *how* but also *when* (and *why*) to use a certain tool. However, Borror *et al.* (2012) considered that the focus should be on moving students from *users* of tools to innovative problem-solvers. After all, the ultimate goal is to prepare students to confidently and effectively approach and solve complex problems (Borror *et al.*, 2012). This goal, however, triggers a two-sided problem as explained below.

On the practical side, scholars and practitioners have recognized that graduates need to be more much work ready, with better leadership and management skills (Thomas *et al.*, 2017), and in particular, with professional (or "soft") skills. The problem is that developing such skills is difficult for several reasons. Educators face the struggle on clearly defining what entails to be "professionally" skilled, followed by their view of professional skills are not core to the discipline taught, and the limited room they have in the curriculum to develop these skills (Gilbuena *et al.*, 2015). Despite this, the most commonly cited professional skills in the literature are related to effective communication (verbal and written), creativity, dynamism, teamwork, resilience, flexibility, customer focus, and participation (National Academy of Engineers, 2004; Anderson-Cook *et al.*, 2012; Weinstein *et al.*, 2008).

On the theoretical side of the problem, the challenge is not only in developing relevant, state-of-the-art curricula but also in delivering its content in a way that fosters personalized learning experience, lifelong learning, and self-education (Langstrand *et al.*, 2015; National Academy of Engineers, 2004; Anderson-Cook *et al.*, 2012). Weinstein *et al.* (2008) recognized that universities should offer more programs that match industry needs (Thomas *et al.*, 2017). Likewise, Borror *et al.* (2012) considered that academic programs must keep evolving at the pace of change in businesses/industry.

In keeping the pace of the rapid change in industry, university–industry partnerships appear critical. Contrary to the traditional classroom setting, which typically consists of lectures, presentation of examples, and case studies (Kanigolla *et al.*, 2014), university–industry partnerships encourage a blended knowledge delivery with a larger element of practical sessions, typically framed in a problem-based learning approach. This, in turn, brings more experience in real-world environments to the classroom setting (Thomas *et al.*, 2017). Despite this, some scholars have recognized the difficulty of synchronizing the business partner's agenda with the academic calendar (Weinstein *et al.*, 2008; Langstrand *et al.*, 2015). In particular, if the course is project-based, it is difficult to identify and narrow scope a project that is both meaningful enough to the industry partner to allocate staff resources and aligned to the course learning outcomes.

In an effort to addressing the challenges above mentioned, we propose a framework, dubbed as EAG^{2}ER, for improving the quality of the engineering design capstone student experience with Lean Six Sigma (LSS) while promoting synergistic university–industry collaborations. We recognize that the idea of using LSS projects in the curriculum (LeMahieu *et al.*, 2017; Kanigolla *et al.*, 2014) nor the elements of our proposed approach are not new just as six sigma involved a methodology comprised of tools that were not new either. However, the framework we propose is based on the synthesis of the literature reviewed and insights from currently available theories on process improvement and project management, an in-depth analysis of project student outcomes, and our own experience, and has proved effective at the undergraduate level. The application of EAG^{2}ER to an engineering capstone course in engineering and management program proved effective for:

- replicating the work conditions in which students will be exposed to after graduation;
- appropriately balancing the theoretical, foundational knowledge with hands-on, real-world experiences;
- providing an industry-recognized Green Belt LSS certification to undergraduate students; and
- promoting academia-industry synergistic collaborations.

Our framework promotes the environment for successful application of LSS and has proved successful with a 100 per cent certification rate in students. After presenting and illustrating EAG^{2}ER, the paper presents a discussion of the implications for practice for both universities and partnering organizations. Last, we present concluding remarks.

Literature review

In an effort to bridging the gap between theory and practice, educators have primarily adopted the PBL approach (Bell, 2010) and recommended to design appropriate curriculum structure (Borror *et al.*, 2012). PBL is a student-driven, teacher-facilitated approach to learning (Bell, 2010). Projects can be industry-led, typically by local companies or small and medium enterprises (Hegarty and Johnston, 2008), or student-initiated (Borror *et al.*, 2012; Weinstein *et al.*, 2008). According to research, students feel more involved in the learning process when PBL is used as they are actively participating in the application of knowledge. Among the reported outcomes of PBL are a greater understanding of a topic, increased student engagement and motivation to learn, and better researchers and problem-solvers (Bell, 2010).

In improving the acquisition/development process of problem-solving skills in students, educators have underscored the need for including in the curricula improvement methodologies such as Six Sigma (SS), lean or a combination of both (Mitra, 2004; Svensson *et al.*, 2015; Shokri and Nabhani, 2015; Anderson-Cook *et al.*, 2005). Some authors have leveraged the natural overlapping between the project-by-project focus of these improvement methodologies and PBL (Kanigolla *et al.*, 2014; Cudney and Kanigolla, 2014; Weinstein *et al.*, 2008). As Montgomery *et al.* (2005) explained, projects are the means to converting conceptual knowledge of methods and techniques into working knowledge to achieve a specific goal. Likewise, Anderson-Cook *et al.* (2005) considered that projects are central to the success of any SS-based course since they provide hands-on experience with the application of tools to solve a problem specifically oriented to satisfy customers' needs.

Overall, the value and benefits that lean and SS bring to both business and engineering programs at the undergraduate and graduate levels are well known in the academic community. However, our literature review suggests a slight preference for graduate over undergraduate programs for conducting SS/LSS projects. For instance, projects have been used in SS and DFSS engineering graduate-level courses (Cudney and Kanigolla, 2014; Kanigolla *et al.*, 2014; Montgomery *et al.*, 2005). Total quality management and SS have been integrated into MBA courses through the execution of projects. In one particular case, MBA students have to propose their own SS projects. While this option was viable for most graduate students who had full-time jobs, Weinstein *et al.* (2008) recognized that identifying and completing SS projects in an academic semester is an extremely difficult task. Likewise, Langstrand *et al.* (2015) acknowledged that obtaining and measuring real process data is too time-consuming for a short course and advanced statistical tools are often difficult to use in projects with limited data. To overcome these difficulties, instructors in Linköping University, Sweden used a real problem, already solved in real-life, to create fictitious data for the projects assigned to students. The authors claimed that their approach contributed to a better learning experience and more commitment from both the instructor and students. Yet, designing solutions based on fictitious data appears insufficient for bridging the gap between theory and practice. After all, an SS project is meant to solve a problem, and a problem is not solved until the solution is confirmed and implemented, and the process change is sustained over time so the problem does reoccur.

An alternative approach to overcome project execution challenges in classroom environments was used in an SS course at Virginia Tech, which involved two projects. The first generic project is a well-defined and narrowed scoped in which student teams solved independently. The second project involved real-world data, but because of the large scope, students did not complete the entire SS process improvement roadmap, namely the DMAIC. They were mainly focused on the Measure and Analyze phases (Anderson-Cook *et al.*, 2005). Even though having two complementary projects offers a valuable hands-on experience, the downside of this approach is that students do not get the opportunity to test the effectiveness of their solutions. Although valuable, working mostly on the root-cause finding and design of a recommended list solutions is insufficient to the eyes of the practitioners. Benefits are not accrued until solutions are implemented.

While the technical aspects in the above-described cases were kept and the student learning experience was improved, the limited project execution approach thwarts the opportunity for further developing "professional or soft" skills in students. For example, giving students a defined problem takes away the learning opportunity of project scoping and gaining a shared understanding of the problem from ill-defined, unstructured problematic situations. Similarly, supplying the data, fictitious or real, to students for their analysis, narrows the learning opportunity of identifying first what needs to be measured and then designing a data collection plan. Data ARE fundamental to understand the current state just as a clear understanding of the current situation is necessary to ignite the iterative inquiry process for determining the root-cause of the problem. Last, removing the solution validation from the Improve phase is also undesirable. Students need to close the learning loop by testing and validating the extent to which their solutions work. Solution acceptance or buy-in, standardization, and sustainability are also valuable learning lessons students set aside if the Control stage of the DMAIC is dismissed.

From the literature review, we also identified opportunities for improvement in the approaches developed for bridging the gap between practice and theory. First, a project infrastructure appears necessary to sustain industry-led project-based courses. Infrastructure supports the project identification, scoping and matching to all parties' needs and expectations as well as the administrative help and provision of subject matter expertise. Projects should be carefully selected, as they are means for students to demonstrate competency. However, project experience can be disappointing if students are not provided with well planned, challenging projects and lack the guidance throughout the execution of projects. According to Cudney and Kanigolla (2014) projects should be selected such that they touch on multiple engineering principles. Aligned to this idea, Weinstein *et al.* (2008) developed a set of guidelines to help industry partners identify projects. Kanigolla *et al.* (2014) recognized the need for engaging both industry partners and students such as having already a pool of projects from which the students could select from. The authors also recognized that more work needs to be done to address the frustration experienced by the perceived "lack" of guidance of students due to the ambiguity of the project. Cudney and Kanigolla (2014) recommended to develop project guidelines to clarify expectations. Another area of concern is related to the constrained time to complete projects. Once the project is assigned to students, project progress is contingent on the availability of the company project champions/sponsors and release of company data to students. Project progress also depends on the semester-long student team members' time commitment and accountability. Project teams experience an accelerated developmental process of team maturation that starts from uncoordinated groups to eventually become an empowered team, which tend to happen towards the end of the academic semester (Weinstein *et al.*, 2008).

EAG^{2}ER: a framework for improving engineering capstone design experiences

This section presents the stages of the proposed framework, EAG^{2}ER, that 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.

Explore the potential collaboration opportunity

Successful project-based collaborations satisfy the needs of both the industry collaborator and students. While educators have a clear understanding of the academic needs, industry needs should be identified, including the work environment, constraints and expectations so that synergies can be identified (Plewa *et al.*, 2013). Ideal industry collaborators are, typically, in a continuous battle for talented graduates and struggle to deploy quality improvement initiatives. Thus, partnering with universities by sponsoring or hosting LSS capstone projects offers an excellent opportunity for connecting with students all semester-long, gaining brand-recognition, and witnessing first-hand the competencies of students. University–industry partnerships can also be used as a low-cost mechanism to ignite the continuous improvement effort in companies. Once the connection has been made, and as shown in Figure 1, this exploratory phase is based on good and frequent bi-directional communication. Transparency is crucial for clarifying expectations and start building trust.

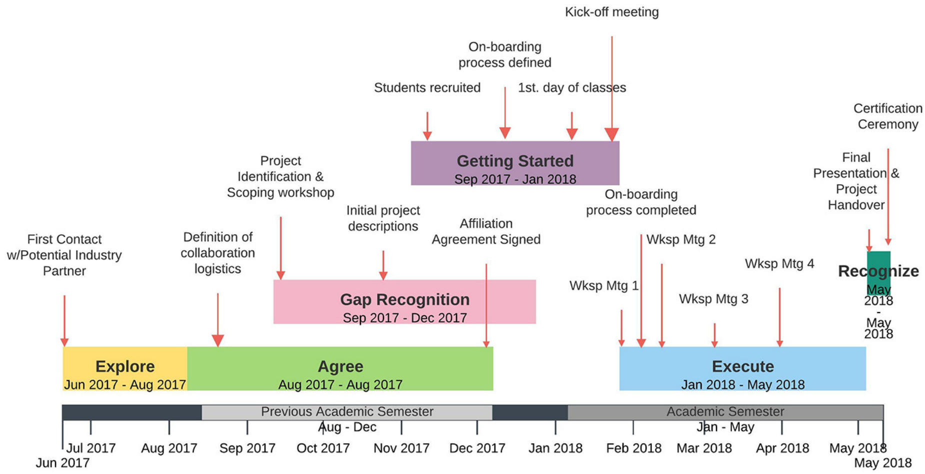

Figure 1.
EAG^{2}ER roadmap

Agree to collaborate

An affiliation agreement or contract is essential to formalize the collaboration. The agreement should make explicit the mutual expectations; type of projects; scope of projects; project deliverables; timeframes; onboarding process for students; allocated resources for both parties (e.g. how many students assigned per project and projects per semester, how many hours will be dedicated to the project and how students are selected); liability issues (e.g. compliance of relevant state and federal confidentiality laws to the extent applicable, training, project feedback, data available, etc.); and, most importantly, the obligations for students and faculty, industry partner's leadership team and staff involved in the projects. After signing the affiliation agreement, which designates commitment and obligation, the point of contacts from each entity should be clearly identified in this stage.

Recognize gaps

This phase entails the identification, prioritization, and selection of projects. The industry partner should drive these three processes while facilitated by the university. The goal is to get the right projects, that is, to select meaningful projects to both the industry partner and students. Choosing the right project is key to the success of the collaboration and an "optimal" capstone design experience (Marin *et al.*, 1999). Overall, projects should be aimed to solve open-ended problems from existing processes with unknown causes and a no predetermined solutions, aligned to business indicators, and addressable in a team environment in three to four months. In offering an optimal capstone design experience, the execution of the project must imply the integration of principles, concepts, and techniques not only in LSS but also in earlier engineering undergraduate courses (Marin *et al.*, 1999).

Table I shows an example of the criteria for the systematic project prioritization. Each project idea is evaluated on a five-point Likert scale to indicate the extent to which each project idea contributes to the criteria. The project ideas with the highest scores are considered for university approval. One of the key characteristics of feasible projects for university–industry collaborations is the match of the timeliness of the project needs to the academic semester schedule. Another critical factor is the availability of staff and project data. Without the alignment and availability of time, people, and data, the project progress is compromised, and the execution of the DMAIC can get jeopardized.

The deliverable of this stage is a project portfolio along with the project charts for the top three projects. A project charter, at a higher-level, is a description of the selected problem or opportunity for improvement that specifies the value to the business, goals, expected benefits, constraints, assumptions and key team players. The project executive sponsor and the project champion for each project should also be selected at this point.

Problem relevance	Project success
Impact on customers/patients	Team availability
Affects safety	Data availability
High volume	Aligned with corporate/strategic goals
Over budget	Investment
Demand exceeds capacity	Controllability of inputs
Customer/Patient dissatisfier	
Staff dissatisfier	
Problematic, never goes right	

Table I.
Example of the project prioritization criteria

Getting started
This phase entails the preparation activities for the execution of the DMAIC and starts with the recruitment of team members (students and staff.) The industry partner's project champion is responsible for recruiting staff team members whereas the university (instructor or program coordinator) is responsible for recruiting senior undergraduate students. Then, selected students complete the industry partner's onboarding process. Class expectations (including evaluation and certification criteria) and additional background information regarding the projects are discussed, and teams are formed and assigned to projects on the first day of classes.

This stage ends with a kickoff meeting where project executive sponsors, champions, process owners, staff and student team members are introduced to each other. The objective of this session is to lay out expectations and have the leadership emphasize the importance of this effort. Roles and responsibilities, collaboration rules are also explained to the participants as well as the project schedule. It is emphasized that this not be a "student" project, nor a "staff" project, but a joint project where true collaboration needs to take place for the completion of the project. As such, time commitments are discussed. The meeting ends with a breakout session in which every staff team member has the opportunity to articulate their "pain" suffered from the problem, and students get the opportunity to ask questions.

Execute the Lean Six Sigma capstone project
The project execution is grounded in four main core pedagogical strategies: flipped classroom, guided student project interventions, project mentoring and constructive feedback. These strategies contribute towards shifting the focus from the instructor as the primary knowledge provider to students as active and engaged learners.

The *flipped classroom* allows to use class time mainly for discussions on the DMAIC applied to their projects. Since students still need to get the theoretical principles of the DMAIC, they take the online, asynchronous, Web-based LSS training outside the classroom. To guarantee that students are held accountable for their self-training at the pace needed for the project, quiz modules and progress reports are used as assessment and control mechanisms.

Guided interventions occur during weekly meetings with students and monthly general workshop meetings with company staff and student team members, process owners, and project champions. Weekly meetings allow students to openly discuss with the instructor the pains of team building as well as to how to overcome natural team dynamics conflicts. These student interactions are excellent opportunities for assessing, identifying, and predicting team struggles, misconceptions of LSS and project roadblocks. The insights gained from these assessments can be used to design/redesign the content for the monthly meetings.

The agenda for the monthly meetings starts and ends with the teams' presentations about their project progress and the team's work plan for the next couple of weeks. Having staff and student team members present their progress to the group is a great opportunity for them to practice their communication, team building and leadership skills. These teams' presentations are progress checkpoints where main obstacles and hindrances are discussed with project leaders/champions/owners on site. Team members also learn about how the other teams are applying the DMAIC to their projects. These presentations promote critical thinking as the student and staff audience questions the other team's work. After the team presentations, an hour to one and half hours of instruction follow. The instructional content is customized to the needs of the project teams already identified during the weekly meetings with students.

Project mentoring is aligned to Levin's (2011) definition, where one experienced person in LSS (in our case the instructor) assists less experienced team members (mainly students) in various technical and nontechnical tasks (e.g. stakeholder management, change management and communication) related to the execution of their projects. Overall, the goal of the instructor mentorship is to ensure a cohesive, effective, and collaborative project executions, keep the team focused and on the right direction.

Clear and opportune *constructive feedback* is pivotal for creating an appropriate learning experience that not only keeps students engaged but also gives them the opportunity to fail. After all, the opportunity to make mistakes is part of the learning and problem-solving process. It is in these low points, where instructor mentorship is meant to provide personal support and guidance for students to overcome such challenges. While the instructor is mentally involved in the project, the instructor participates from the sidelines at all times.

In keeping track of the project deliverables, students prepare five tollgate reports that are submitted to the instructor for *constructive feedback*. The objective is to guide students in their correct application of the DMAIC tools, avoid isolated tool implementations, and appropriately report and communicate their results in written and oral formats. Given the tight agenda of the project, the feedback turnaround time should be short, ideally within a couple of days. According to Langstrand *et al.* (2015), prompt feedback helps to ensure that students have not moved on to new tasks and should always be accompanied with the positive aspects of the students' performance to strengthen their confidence. This iterative feedback/tollgate revision approach stimulates reflection, critical thinking and, ultimately, learning.

Realize and reward

This phase entails the dissemination of the project results, project handover to the industry partner, and a recognition (or certification) ceremony. Dissemination activities include the final project presentation, finalization of the documentation of the entire DMAIC project report and other external presentations (e.g. professional/research conference.)

The final presentation is the opportunity team members have to tell their improvement story from beginning to end, demonstrate their operational and financial benefits and provide advise for solution sustainability. When both student and staff team members give the presentation, it reflects their genuine collaborative project work. The emphasis here is placed not only in the problem solved but also in the thought process that led the team to fix the problematic situation. The final project presentation also represents the official project handover to the process owner for its full implementation and seamless integration into their everyday business operations.

Regarding the certification, and as noted in the literature, there is a high variation in LSS certification standards that makes the assessment of the actual competence of a certified GB difficult (Laureani and Antony, 2011). As noted by Antony *et al.* (2017), there are some certifications on the market that do not even require to prospective GBs to prove the technical competency through the completion of a project or passing certification exams. Therefore, it in this framework, we propose the use of a third-party LSS GB certification program, preferably accredited by the International Association for Six Sigma Certification, the International Association for Continuing Education and Training and the American National Standards Institute. This will provide undergraduate engineering students with a prestigious and well-accepted GB certification in the industry sector. Once students complete the industry-standard certification requirements for GB LSS, students are recognized for this achievement in a certification ceremony.

Case study

The proposed framework was applied to an Engineering and Management capstone design course offered in Spring 2018 at the author's university. Figure 2 presents the timeline and major events of each phase of EAG^{2}ER. The timeline reveals that the phases prior the execution of the projects overlapped and took place during the summer and fall of 2017. It is also noted that the agreement stage was the longest of all phases due to the delay in formalizing the agreement with a contract that was finally signed in December 2017.

In understanding the needs of the industry partners, which in this case was a rural hospital and a clinical health center located in Upstate New York, the author identified the need for delivering a workshop on project identification to the leadership team. In this workshop, it was also emphasized the need for data and staff availability for the projects as outlined in Table I.

The delay in signing the affiliation agreement prevented students from completing the onboarding process by the first day of classes. They completed the onboarding three weeks after the project had officially started. Even though we had a kickoff meeting and students heard firsthand the effects of the problem from multiple stakeholders, process owners and leadership, they could not go to the *gemba* or have access to process data until all of them were cleared up. Nonetheless, students started mapping the process based on the staff members' and other stakeholders' perceptions that were soon updated according to the students' observations of the actual process. A full description of the projects completed is beyond the scope of this paper; therefore, we provide brief highlights of some projects:

- reduction in the average time and variability for inter-hospital patient transfers;
- reduction of late starts times of ambulatory surgeries;
- reduction in the average time and variability for transferring emergency department (ED) patients to the intense care unit (ICU) within the same hospital; and
- improvement in the information accuracy of the patient registration process.

The structure of the execute phase consisted of four four-hour workshops scheduled every three or four weeks, weekly mentoring meetings with students, weekly working sessions

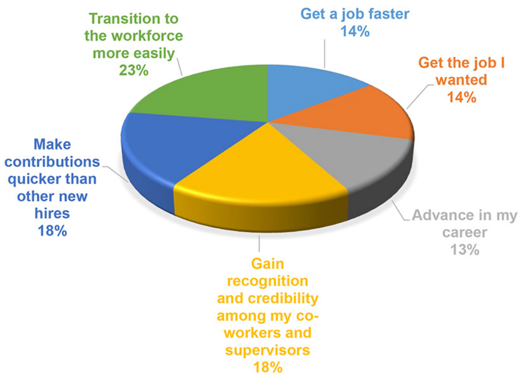

Figure 2.
EAG^{2}ER timeline

Question	Group	Strongly disagree	Disagree (%)	Neutral (%)	Agree (%)	Strongly agree (%)
I felt my capstone project helped me understand better how to apply theoretical models or concepts to real-world situations	LSS				28	72
	Other		13		55	32
I was able to apply E&M concepts and theories as a result of working on my capstone project	LSS				40	60
	Other		4		83	13
My capstone added a lot of realism to the course	LSS				18	82
	Other		4	4	50	42
My capstone project helped me to become a better problem-solver	LSS				22	78
	Other		8		54	38
My capstone project helped me become a more data-driven thinker	LSS				29	71
	Other		5	30	60	5
My capstone project allowed me to view an issue from multiple perspectives	LSS				24	76
	Other		8		54	38
I felt my capstone project experience has helped me become a better leader/project manager	LSS				53	47
	Other		5	11	79	5
I felt my capstone project was an optimal learning experience	LSS				29	71
	Other		10		75	15

Table II.
Percentage responses for LSS and other capstone courses

with hospital staff, and on-site work such as process observations, data collection and analysis. Topics discussed in these workshops ranged from project redefinition, process mapping, data collection, validation, and analysis, root-cause analysis, solution brainstorming and evaluation, standardizing work, change management and control mechanisms. Even though the four-hour workshops were "mandatory" sessions for all team members as well as project champions and process owners, some staff team members partially or entirely missed some of these meetings. As a result, the team progress was severely compromised, leading to additional work sessions. Parallel to this work, students were also working on their web-based GB LSS training.

The instructor's role was critical. The guided interventions had the objective of keeping the teams focused and on track content- and time-wise. As noted by Laux *et al.* (2015), GBs have strong motivations to complete projects successfully and may exhibit a strong start. However, as time progresses and barriers arise, the attention to the project timeliness to meet projected goals diminishes. The expert opinion states that project success requires a sense of urgency to complete projects within three to six months (Antony *et al.*, 2017). However, a study revealed that GBs typically take over nine months to complete their projects, mainly due to the time constraints of the project team members (Laux *et al.*, 2015). In our case, we barely had four months to complete the projects. Students had to finish their project to get a passing grade, and therefore graduate. This fact certainly puts some pressure on the hospital staff team members too. They did not want their lack of commitment to their project to impede their student team members' graduation. Thus, every week the team had to make some progress in the right direction.

This "pressurized" effort resulted in all projects to be completed, meaning that they achieved their objectives and were approved by the third-party LSS certifying company during the final exam week. That is, within fourteen weeks all projects brought tangible results to the hospital and clinical health center. In addition, during this same week, all

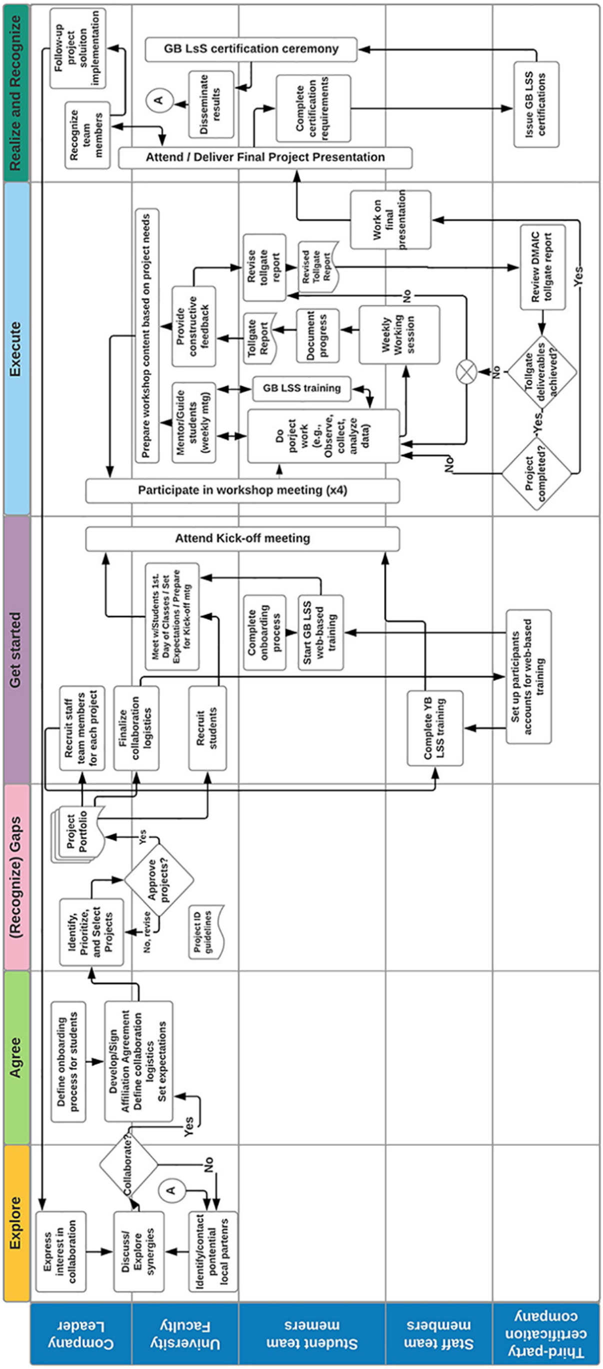

Figure 3.
Lean Six Sigma green belt certification reported benefits on early stages of students' careers

students passed their certification exams, which in turn resulted in a 100 per cent certification rate. Overall, this real world, semester-long project enhanced the learning experience of students. As 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. Some examples of their feedback are shown in Students' comments at the course completion.

> Most valuable course I have ever taken. The certification is so valuable and just makes [University name] students above the rest. Great experience with process improvement, team building, and real-life application. Most rewarding senior capstone project I believe.

> I am very happy I chose this capstone class. I have learned a lot about Lean Six Sigma and feel very confident using this in the real world. The ability to get my green belt is awesome.

> Great opportunity for students. So applicable to the working field. Taught me a lot about working with a company team and different methods for solving problems.

> This course allows students to apply the knowledge from class in depth. It is both challenging and rewarding. In addition, it allows students to strengthen communication, leadership and collaborative skills.

> I feel very ready to begin working full-time with all the knowledge I absorbed from this course. It was extremely beneficial.

However, the execution of projects was not an easy journey as there were process, time and data constraints. Certainly, the late onboarding process completion delayed the project groundwork. Regarding the process data, the hospital had historical data, but it was at an aggregate level, not at a process level. In other cases, process data was inaccurate or incomplete. Therefore, students had to manually collect data while staff members worked with IT to pull the required process time-stamps of patients needed for the process under study, fix the information system, or re-train people to enter data correctly into the system. Another lesson learned was to require flexible champions, process owner, and staff. While they were sensitive to the timeliness of the project, they inarguably missed some of the workshops and meetings with students. The staff team members' absenteeism slowed the project progress pace and overloaded students with additional meetings. Therefore, it underscores the need for project champions and leaders properly release staff team members from their duties for a few hours a week so that they can attend the meetings. Another lesson learned was regarding the unavoidable, uneven contribution of some students to the project. Even though all had the desire to get the GB LSS certification, some of them took it for granted. Therefore, the instructor had to intervene to fix this situation. In the two observed cases, students dramatically changed and completely took ownership of the project. Therefore, certification should be used as an incentive. A student nomination system based on peer reviews and overall contribution to the project would be beneficial to recognize the work of students with the GB LSS certification.

Conclusion

This paper presented a framework for executing LSS engineering capstone projects through university–industry partnerships. The six phases of the framework are dubbed as EAG^{2}ER, which stands for explore (potential collaboration), agree (to collaborate), recognize gaps, get started, execute (the project), and realize and reward (project achievements.) For the university, this approach contributes to shifting the focus from the teacher as the primary knowledge provider to students as active learning participants. For the industry partner, EAG^{2}ER represents a low-cost and -risk approach to raising awareness and experiencing LSS benefits through accelerated, reinforced, and guided project executions. Key to this framework is to pair meaningful industry projects with a genuine collaboration based on guided student interventions, mentoring, and constructive feedback. The framework was illustrated with an application to an engineering and management capstone design course. We believe the case presented here is a good example of how industry and academia can work together towards bridging the gap between theory and knowledge. The fact that students were involved from definition to implementation of the LSS project 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. After all, we believe EAG^{2}ER enhanced students' preparedness to work environments that call for collaborative, negotiating, planning, data-driven and organizational skills, all of which were practiced during their LSS project as part of their engineering capstone project.

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