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Incorporating a Unique Lean Six Sigma Learning Experience by Integrating Graduate and Undergraduate Students Across Two Lean Six Sigma Courses in the Engineering Technology and Engineering Management Curriculum

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Abstract

The purpose of this study is to incorporate a rather unique experiential learning experience into two Lean Six Sigma courses, one at the undergraduate level in an engineering technology program, the second in a graduate-level engineering management program, residing in the same department. The Engineering Management, Systems and Technology Department at the University offers a Lean Six Sigma course within the undergraduate engineering technology programs and as part of the graduate Engineering Management and Management Science programs. We integrated the undergraduate and graduate students across the two courses and two sections during the Fall 2020 semester. This enabled both undergraduate and graduate students to work together on real-world service-based lean six sigma projects. The undergraduate course covered a Six Sigma Green Belt curriculum, and the graduate course incorporated additional Six Sigma Black Belt tools. The student teams worked on 6 different Lean Six Sigma projects. For five of the six projects, two separate teams worked on each project, meeting with stakeholders and process owners together, to reduce the redundancy of the material covered. For comparison purposes, there were three undergraduate students only project teams, two graduate students only project teams, and six combined undergraduate and graduate student teams. A Six Sigma Master Black Belt separate from the instructor mentored the students on their projects, and assessed their ability to apply the Lean Six Sigma tools and the DMAIC (Define-Measure-Analyze-Improve-Control) methodology. We will assess the student performance on applying the Lean Six Sigma DMAIC methodology and tools, based on both the Six Sigma Master Black Belt mentor feedback, and student final report results at the end of the Fall 2020 semester.

Introduction

The Department of Engineering Management, Systems and Technology program at the university offers a Lean Six Sigma (LSS) course for both undergraduate and graduate students. The class is designed to learn useful tools for process improvement and variation/waste reduction by integrating Six Sigma methodologies with lean principles. More importantly, the goal of the course is to give a unique opportunity for students to work on a real-world project in manufacturing and service systems so that they can apply the method and tools of the LSS DMAIC (Define-Measure-Analyze-Improve-Control) and other strategies, such as team building, through the project.

During the Fall 2020 semester, the undergraduate and graduate students across the two courses were integrated into two sections, which makes them work together as a group for the Lean Six Sigma project. There were six student teams in a section, working for the six different topics on and off the campus. The same topic was assigned to the two teams from the two sections, which enabled us to compare the performance of the two groups side-by-side. Students were asked to work on the group project based on the DMAIC methodology of Six Sigma, and hence the student performance was also assessed accordingly. Student grades were quantitatively evaluated by a Six Sigma Master Black Belt as well as the instructor of the course to gain even greater credibility to the study results.

The main objective of this paper is to obtain valuable insights on educating students in a more diverse Lean Six Sigma experiential learning environment by integrating our undergraduate students who tend to be domestic US students with our more diverse international graduate students. Although it is widely accepted that graduate students usually perform better than undergraduates in course work, not much is known if there is a synergy when undergraduates and graduates are assigned in the same group. For that purpose, two different setups were applied: there were undergraduate students only project teams and graduate students only project teams in one section, while there were six combined undergraduate and graduate student teams in the other.

In this research, we investigate two different hypotheses about groups setup: (1) groups in which undergraduate and graduate students are combined perform better than undergraduate- or graduate-only groups and (2) when there are graduate students in a team, groups of more graduate students perform better. Findings about the group construction for the team project in this research can also be very useful when establishing undergraduate/graduate integrated courses in the department. After an overview of the project, the quantitative analysis tool used and its results are presented. Finally, the conclusion follows with a discussion of the results and future plans to improve the course and its assessment methods.

Literature Review

Experiential learning or project-based learning has been widely employed in teaching Lean manufacturing and Six Sigma courses. It helps students learn core concepts of LSS and allows for deeper understanding of the theoretical knowledge through the practical application. Van Til et al. (2009) discussed design and implementation of a problem-solving Lean project in an interdisciplinary course taught by a faculty team from different schools. Montgomery et al. (2005) described the introduction of Six Sigma program and its coursework and project activities required for the Black Belt certification. Kanigolla et al. (2014) showed that the semester project had a positive impact on the students' knowledge in learning key concepts in both the Lean and Six Sigma courses. They collected student feedback and conducted a statistical analysis to study how engaged the students were through the project.

In a course setup where undergraduate and graduate students are taking the class at the same time, it should be considered how groups are formed so as to maximize students' learning ability. In many previous studies, it has been broadly investigated the role of graduate students in a team project and interactions between undergraduate and graduate students. For instance, Belu (2019) considered a project-based learning in a power electronic system course. Schreuders et al. (2002) discussed integration of graduate and undergraduate students in developing a computer simulation model in an ecological engineering project. In their study, graduate students were required to conduct analysis, while undergraduate students were assigned to relatively simple tasks, measurement.

The idea of graduate students taking a different role in a project setting is studied by others as well. Barker and Pitts (1997) discussed a role of graduate students as mentors to undergraduate students in an MBA capstone project. Graduate students can even take a greater role in self-learning methods. As Brown and Pastel (2009) discussed, they can make a presentation to the class so that students can share their skill sets and human-computer interaction (HCI) design implementation in a software engineering class. In this study, we will investigate whether having graduate students in a student team leads to better team performance in comparison to the teams without graduate students.

Method

Overview of the Lean Six Sigma Group Project

The Lean Six Sigma project is designed to provide an experiential learning opportunity to students. Typically, the topics are relevant but not limited to manufacturing, quality inspection, service enterprise in which its process suffers for inefficiency, variability and waste so that Lean and Six Sigma tools and methodologies can contribute to process improvement. The Lean Six Sigma project topics were selected on and off the campus. Six selected project topics for the Fall 2020 semester included as follows:

- UD New Employee On-Boarding Process
- County Court Juvenile Mentoring Program Male Mentor Recruitment
- University Bookstore Order Processing System
- Electric Motor Manufacturing Company
- Department Faculty Summer Payment Process
- Department Adjunct Faculty Hiring Process

As mentioned earlier, there were three undergraduate students only project teams, two graduate students only project teams, and six combined undergraduate and graduate student teams. The project topics are largely assigned to the teams randomly, except for the industry project in which students with specific skillsets and experience were considered. Topic assigned to the project teams and composition of groups are summarized in Table 1 below:

Table 1 Lean Six Sigma Project Teams

Topic	**Team #**	**Section A**	**Team #**	**Section B**
1. UD New Employee On-Boarding Process	A1	5 UG (1 FR, 1 JR, 3 SR)	B1	2 UG (1 JR, 1 SR) + 3 GR
2. County Juvenile Court Mentoring Program Mentor Recruitment	A2	5 UG (1 SO, 2 JR, 2 SR)	B2	1 UG (1 SR) + 4 GR
3. University Bookstore Order Processing System	A3	5 UG (1 JR, 4 SR)	B3	2 UG (2 SR) + 3 GR
4. Electric Motor Manufacturing Company	A4	3 UG (3 SR) 1 GR	B4	2 UG (2 SR) + 3 GR
5. Department Faculty Summer Payment Process	A5	5 GR	B5	2 UG (2 SR) + 3 GR
6. Department Adjunct Faculty Hiring Process	A6	5 GR		N/A

NOTE: UG = Undergraduate Students; GR = Graduate Students

Grading Rubric and Peer Assessment

Each project team was asked to apply the DMAIC problem solving methodology to synthesize the course contents and write a report describing the project in detail. A grading rubric was used that identified the tools and techniques for each phase, and team performance for each phase was assessed based on the items shown in the rubric. Table 2 shows part of the rubric used for assessment.

Table 2 Part of the Grading Rubric for Assessment

Criteria	**Grading Rubric for Define Phase**	**Points Available**	**Points Given**	**Comments**
Quality of report content and grammar	(8 – 10) Concise, description of each tool, describe key findings regarding tool, well written and organized. (5 – 7) Does not thoroughly discuss the topic, missing key findings, and/or poorly written (2 – 4) Poorly written, lacking detail, missing description of tool and/or findings (0 – 1) Missing or superficial	10		
Project Charter (problem	(16 – 20) Well-defined problem overview, statement, goals and scope. Problem statement describes the problem while	20		

Criteria	Grading Rubric for Define Phase	Points Available	Points Given	Comments
overview, problem statement, goals, scope)	being specific, describing the magnitude of the problem quantitatively, and with time-based measure. Goals are SMART (Specific, Measurable, Attainable, Realistic and Time-based). Scope is reasonable for the semester project timeframe, describing what is in scope from a process perspective and what is not included in the scope. (11 – 15) Less thorough description of the problem, not very specific, no or little description of the magnitude of the problem without a time-based measure. Goals are not SMART. Scope is too large or too small. (0 – 10) Lacks detailed description of the problem overview, statement, goals and scope			
Critical to Satisfaction (CTS)	(8 – 10) Sound description of the Critical to Satisfaction, capturing what is critical to satisfaction, quality, delivery/timeliness, cost, process or safety. Focused on the output or outcomes. (5 – 7) Inadequate description of the CTS, don't align to satisfaction, quality, delivery/ timeliness, cost, process or safety. Not focused on output or outcomes. (0 – 4) Missing or very poor CTS.	10		

Teams were expected to delegate the tools across team members equally, and individual students were accountable for assigned tools. In order to ensure that every student in a team equally contributed to not only writing a report but in the discussions and other team activities, peer assessment was conducted at every phase of the DMAIC methodology. Expectations of applying peer review were mainly to increase student accountability and avoid social loafing because non-contributors still could earn the same grade, which could make a negative influence on group experience and engagement (Hall and Buzwell 2012).

The assessments across all team members within each project were averaged and multiplied by the Lean Six Sigma project report grades. Thus, a student who made an equal or average contribution to the project receives the group mark, while those who made greater or lesser contributions were awarded more or less than the group mark. This method of multiplication by weighting factor is considered as the most fair and equitable grading for peer assessment by most students (Conway et al. 1993). In addition to peer assessment, students were also asked to share their honest opinions with their team members.

Results

Final Report Grading

Grades of the final report of all teams are summarized in Table 3. Overall, teams with more graduate students tend to perform better for the same project topic. For project topic 1 through 3, student teams in Section B where undergraduate and graduate students are combined outperform undergraduate only project teams in Section A. For the topic 4 and 5, project teams with more graduate students have done a better job in their final report, while the differences in score were not great in both cases.

For topic 2 and 3, however, we found that the project teams with undergraduate and graduate students combined submitted more organized final reports with well-developed tools. They seemed to understand the topics and tools covered in the class and how to apply them in their project, and more importantly, follow the instructions of the rubric. Every member in the team looked actively involved in the group activities according to their peer review. One of the project sponsors was also very impressed by the team's maturity and what students delivered with their teamwork.

Table 3 Final Project Score

Topic	Team #	Section A	Project Score	Team #	Section B	Project Score
1. UD New Employee On-Boarding Process	A1	5 UG (1 FR, 1 JR, 3 SR)	80.17	B1	2 UG (1 JR, 1 SR) + 3 GR	82.58
2. County Court Juvenile Mentoring Program Mentor Recruitment	A2	5 UG (1 SO, 2 JR, 2 SR)	85.75	B2	1 UG (1 SR) + 4 GR	92.5
3. University Bookstore Order Processing System	A3	5 UG (1 JR, 4 SR)	87.08	B3	2 UG (2 SR) + 3 GR	94.08
4. Electric Motor Manufacturing Company (Emerson)	A4	3 UG (3 SR) 1 GR	88.17	B4	2 UG (2 SR) + 3 GR	91.5
5. Department Faculty Summer Payment Process	A5	5 GR	86.75	B5	2 UG (2 SR) + 3 GR	82.17
6. Department Adjunct Faculty Hiring Process	A6	5 GR	87.58		N/A	N/A

NOTE: UG = Undergraduate Students; GR = Graduate Students

It should be noted that both of the groups working on the first project topic obtained relatively low scores compared to others. This might be partly because collaboration with another department in the university delayed the progress of the project in the beginning of the semester, while the team with a mixture of undergraduates and graduates in Section B still performed slightly better. Also, it was reported by the result of peer assessment that student teams A1, A2, and B1 had an issue of social loafing team members whose contribution and engagement were disappointing. It has been shown in previous research that piggy-backing in the team negatively affected other students' ability to learn content-related information (Bacon 2005).

Quantitative Analysis

We conducted a simple mean comparison test on the final project score to investigate whether teams with both graduate and undergraduate students performed better. When we take the teams for Topics 1, 2, 3, and 5 as we both have a combined group for Topic 4, there was a significant difference between the means (p-value = 0.0084), which indicates that the mixed setup of students leads to better performance. Results are summarized in Table *5* Results of the Paired Two Sample for MeansTable 5.

Table 4 Results of the Paired Two Sample for Means

	Teams with UD-GR Combined	*Teams with UD or GR only*
Mean	83.7925	88.9775
Variance	10.13149	28.11109
Observations	4	4
Pearson Correlation	0.996645	
Hypothesized Mean Difference	0	
df	3	
t Stat	-4.83327	
P(T<=t) one-tail	0.008444	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.016887	
t Critical two-tail	3.182446	

Next, we tested another observation that the teams with more graduate students tend to perform better. Considering that the same topic has similar difficulty levels by the nature of the topics, we conducted a paired two sample test for the means. After rearranging the data set for the two teams on the fifth topic as the team in Section A has more graduate students, we found that the teams with more graduate students received a better score on their final reports (p-value = 0.003). Results are summarized in Table 5 Results of the Paired Two Sample for MeansTable 5.

Table 5 Results of the Paired Two Sample for Means

	Teams with Less Graduate Students	*Teams with More Graduate Students*
Mean	84.668	89.482
Variance	11.43112	22.35592
Observations	5	5
Pearson Correlation	0.927257	
Hypothesized Mean Difference	0	
df	4	
t Stat	-5.28996	
P(T<=t) one-tail	0.003064	
t Critical one-tail	2.131847	
P(T<=t) two-tail	0.006129	
t Critical two-tail	2.776445	

To further investigate how much student low involvement explains underperforming of project teams, a simple linear regression analysis is conducted. The peer assessments across all team members tend to have greater variability when students think their team member's contributions were not equally distributed. On the other hand, when all students in a team think they are equally contributing, the variation would be zero. Variations of peer assessment of the teams are summarized in Table 6 below.

Table 6 Variations in Peer Assessment

Topic	**Team #**	**Section A**	**Variation**	**Team #**	**Section B**	**Variation**
1. UD New Employee On-Boarding Process	A1	5 UD (1 FR, 1 JR, 3 SR)	21.369	B1	2 UD (1 JR, 1 SR) + 3 GR	29.047
2. County Court Juvenile Mentoring Program Mentor Recruitment	A2	5 UD (1 SO, 2 JR, 2 SR)	26.648	B2	1 UD (1 SR) + 4 GR	0.308
3. University Bookstore Order Processing System	A3	5 UD (1 JR, 4 SR)	9.740	B3	2 UD (2 SR) + 3 GR	3.461
4. Electric Motor Manufacturing Company	A4	3 UD (3 SR) 1 GR	3.832	B4	2 UD (2 SR) + 3 GR	1.720
5. Department Faculty Summer Payment Process	A5	5 GR	1.746	B5	2 UD (2 SR) + 3 GR	5.181
6. Department Adjunct Faculty Hiring Process	A6	5 GR	1.509		N/A	N/A

We tested whether the variability and the team setup are related, but it was proved to not be the case (p-value = 0.74). Considering the case where the presence of uneven contribution from social loafers leads to greater variability this result makes sense.

A simple linear regression technique was employed to develop a statistical model based on the variability of the team assessment. This result implies that when student assessment to others in the team differs greatly, it can negatively affect the final report score. This result reinforces previous findings on the negative effect of piggy-backing members to other students' ability to learn (Bacon 2005).

WORKSHEET 2

Regression Analysis: Score versus Variability

The regression equation is
Score = 89.69 - 0.2603 Variability

Model Summary

S	R-sq	R-sq(adj)
3.57159	40.92%	34.35%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	79.501	79.5011	6.23	0.034
Error	9	114.806	12.7563		
Total	10	194.307			

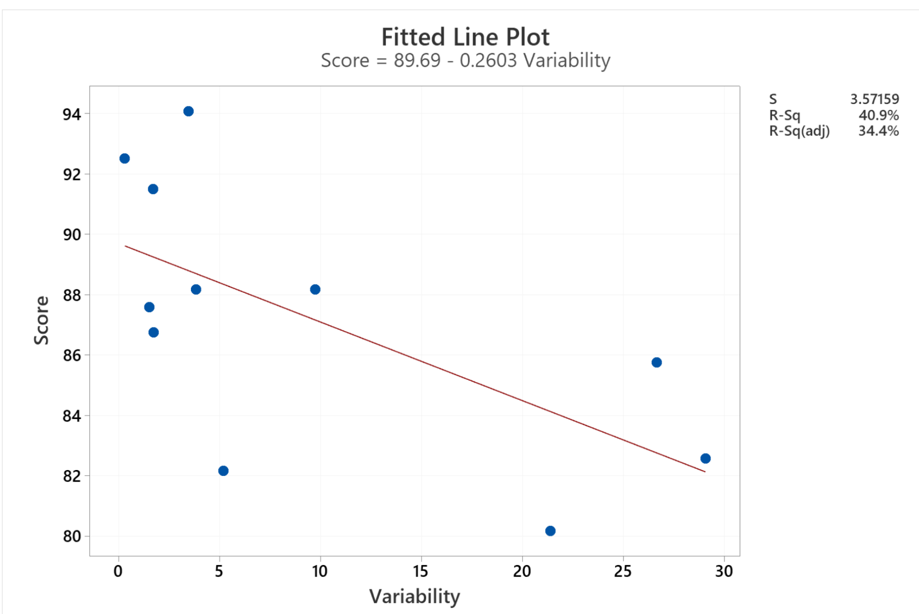

Figure 1 Results of Regression Analysis

Conclusions and Future Work

A semester project has been widely accepted as effective learning tool in Lean Six Sigma courses. Students are expected to apply key concepts and enhance understanding through project activities. However, when undergraduate and graduate students are integrated into the same course, it is unclear how to set up groups by combining two different levels of students to maximize the effectiveness of experiential learning. In this study, we study the group formulation of student teams in a classroom setting to investigate whether combining undergraduate and graduate students leads to better performance. A simple statistical analysis is conducted to test whether a section of teams in which undergraduate and graduate students are combined outperform the other section. The test results indicate that there is support for the hypotheses as (1) groups in which undergraduate and graduate students are combined performed better than undergraduate- or graduate-only groups and (2) when there are graduate students in a team, groups of more graduate students perform better. These are important results from the perspective of the ability to enhance the performance of undergraduate students by providing graduate team members as part of the teams.

This study presents a unique opportunity to combine both graduate and undergraduate in the same class. This interesting pedagogy will be valuable to educating our students in a more diverse Lean Six Sigma experiential learning environment by integrating our undergraduate students who tend to be domestic US students with our more diverse international graduate students. A future goal is, therefore, to develop a survey to comprehend how diversity can affect team's performance in the LSS class.

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