Facilitating Engineering Principles via Industry Standards: The Case of Lean Sigma in a Community College Classroom

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***Abstract*— Opportunities in Science, Technology, Engineering, and Mathematics (STEM) exist now more than ever for students interested in pursuing engineering degrees and careers. Although many of these students have acted on this interest, by enrolling in engineering courses as Freshmen, there are many who struggle with applying the Engineering Design Process to solving complex problems, post-enrollment. This is especially true for First Year Engineering students on the Community College level, where few opportunities for hands-on, project-based learning activities exist, in comparison to Tier1 research universities. The number of students who successfully obtain these design skills at the community college level directly impacts the number of students who are eligible to transfer to, enroll in and pursue Engineering degrees at four-year institutions. The proposed study will explore the introduction of lean six sigma methodologies within an Engineering student's first year, using a hands-on project as a pathway towards enhancing student experiences, learning and motivation in the areas of Engineering Design Process development and implementation. This proposed intervention, focuses on the implementation of instruction and curriculum design changes that serve as a catalyst for closing the education equality gap, where the ability to apply engineering design and process improvement principles are concerned.**

***Keywords* — STEM participation, Six Sigma, Underserved Students, Higher Education**

INTRODUCTION

The Engineering Design Process (EDP) is an essential part of the problem-solving process and a learning objective for engineering students to both grasp and apply. Comprehension of these principles demonstrates that the student is able to make effective decisions in the midst of dynamic and volatile scenarios. This iterative process requires that a student not only understands the full project scope but is able to derive scope details into the requirements and constraints needed to establish the design and subsequent action items. The EDP can be broken into 7 key steps that must be taught sequentially, beginning with Defining the Problem and concluding with iterations and improvements, similar to the Lean Six Sigma lifecycle [10].

To introduce the EDP to students who are just beginning their post-secondary education, this study recommends the immersion of students in Lean Six Sigma (LSS) applications alongside experiential learning activities. Combining LSS with project-based engineering scenarios is a unique merger of continuous improvement techniques with design challenges that unique hands-on activity environments.

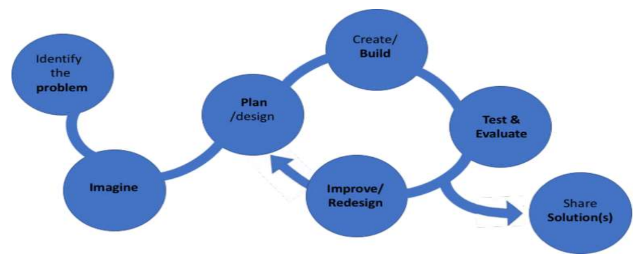

FIG 1: Engineering Design Process Steps [4]

LSS methodology is used by companies competing in global markets that demand exceptionally high quality and less costly products and services [7]. LSS principles follow a defined sequence of steps with measurable goals and financial targets (cost reduction and/or profit increase) and rely on statistical tools to account for variability within a system as well as uncertainty [3]. To successfully implement LSS techniques that support process improvement goals and the establishment of infrastructures that contain specific roles and responsibilities, project leaders often use the DMAIC (Define, Measure, Analyze, Improve, and Control) methodology. Applying the DMAIC methodology to various issues that arise throughout the product lifecycle may assist students with the task of adjudicating process bottlenecks, system errors, and quality defects that occur within the engineering design lifecycle [5].

This author's background is a perfect blend of industry and academia, and her current role as an Associate Professor of Practice, speaks to her ability to connect with the students in a manner that lends itself to workforce and professional development of students. This research was born out of that desire and after observing First Year Engineering (FYE) Students struggle with understanding the EDP from a theoretical perspective for several years, the author decided to alter her curriculum to find a more effective way of teaching. This alteration led to the intervention highlighted in this study and the eventual incorporation of DMAIC methodologies into a hand-on project deeply rooted in the experiential learning approach.

DMAIC	PROCESS DESCRIPTION
Define	Understand the problem, project business case and identify customers
Measure	Outline process steps and quantify the problem
Analyze	Discover the root cause of the problem
Improve	Confirm proposed solution addresses the problem and is applicable and implementable
Control	Maintain and sustain improved solutions

Table 1. DMAIC Process Definitions [5]

Both the DMAIC process and the EDP begin with defining the problem and have mandatory improvement requirements as part of their product life cycle, hence the instructor's decision to overlap the two efforts. As a LSS expert with a Master Black Belt certification, it is the author's belief in pragmatism and being guided by the practical outcomes of research that has influenced this study thus far, from a philosophical perspective. An emphasis on active learning, real-time problem solving and actual industry-based processes, supports the author's unwavering commitment to a project-based scenario for evaluating student interactions, prompting the following research questions:

Research Question 1: How are Lean Six Sigma principles adopted by community college students as part of their first-year engineering experience?

Research Question 2: How are demographic groups showing different perceptions in the adoption of Lean Six Sigma principles?

The proposed LSS based approach to engineering design research focuses on five main areas of instruction within the area of continuous improvement: Design, Measure, Analyze, Improve and Control as it relates to the seven steps of the EDP: Define, Ask, Imagine, Plan, Prototype, Test and Improve [10]. The outcomes of this research have the potential to enhance the design acumen of FYE via experiential learning environments with a focus on teamwork as the foundation for the development of student understanding and implementation of the Engineer Design Process via Lean Six Sigma pathways.

LITERATURE REVIEW

In industrial applications, DMAIC (Design, Measure, Analyze, Improve, and Control) is a Six Sigma tool derived from statistical quality control engineering initiatives that are commonly used for problem-solving [2]. Based on the author's in-class observations and an extensive literature review on both educational and engineering topics, the conclusion was made that students exploring engineering design and learning Six Sigma for the very first time, may need assistance and guidance when attempting to build and maintain interest in these topics. To help prevent discouragement when challenging scenarios arise, mandating a team approach to the LSS project activity could be used as a motivating tactic. This approach promotes collaboration and offer additional support to students who may experience difficulties during the application of the DMAIC process, since much of the ambiguity surrounding the implementation is knowing when to use what tools [6]. Creative exploration projects, like the one designed for this study, provide students with a set of guidelines and materials for them to use while exploring the engineering design process. Along the way, a challenge was introduced, which forces the student to pivot in situ and take a lean six sigma focused approach to solving that challenge with the help of their classmates. Bandura speaks to the impact of social influence when describing various aspects of achievement which were taken into consideration for this study.

THEORETICAL FRAMEWORK

The process of allowing students to plan and "try out" their designs, supports the experiential theory's goal of providing students with concrete learning experiences that allow them to explore and reflect on the results. The social influence Bandura speaks of [1], could also be linked to self-efficacy, when used as a tool for promoting motivation and engagement within applied to learning environments. Furthermore, self-efficacy has also been linked directly to achievement and learning, which the author hopes to demonstrate using Six Sigma methodology and the establishment of teams working on a robotics themed project. This bold approach to group hands on learning opportunities is supported by social cognitive and experiential learning theoretical frameworks and constructs shown in the model below.

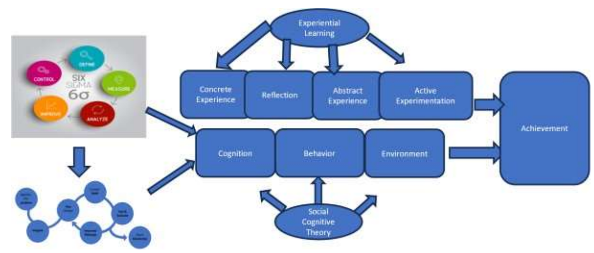

Fig. 2: Framework showing the connection between Lean Six Sigma and the Engineering Design Process, with Experiential and Social Cognitive Theories

Differences in learning styles for each participant were acknowledged, but the focus remains on the commonalities shared during this experience, which include project topic selection, lean six sigma instructional training and team collaboration. To teach students elements of the engineering design process using lean six sigma techniques, a case study was referenced, one that highlights a real-world industry level problem in need of a continuous improvement solution that can not only be implemented but also controlled. Face-to-face lectures of the material were held in a classroom setting, allowing students to learn the new material in a safe space among their peers. Each instructor fostered opportunities for dialogue all while building student confidence in their ability to recall, articulate and apply the DMAIC process of Lean Six Sigma when required.

This research seeks to connect the dots between industry and academia by incorporating Six Sigma principles as a pathway for improving student achievement as it relates to the Engineering Design Process (EDP) overall by establishing a Six Sigma business rhythm early and often. Many of the engineering students participating in this study will matriculate on to industry positions post-graduation, where Six Sigma is part of the standard workflow. Allowing them to experiment with these methodologies as first year students, under the guidance of an industry-trained instructor and under the safety net of team collaboration, could enhance their ability to achieve successful recall and application of this information at a later time. Informing them of the benefits of using DMAIC methodology in their first semester and allowing them to experiment with that methodology individually as part of a team setting, could greatly impact their future academic and professional development going forward.

RESEARCH METHODS AND DESIGN

This study aims to bridge the gap between industry and academia by incorporating Six Sigma into the learning environments of Freshman Engineering classes (i.e., ENGR 102: Computational Analysis) via both inculturation and identity development learning methods under the umbrella of group work and team experiences. This research seeks to identify and measure the improvements that can be made to engineering learning environments when Lean Six Sigma principles and concepts are introduced and infused into the design of instruction for first year students. Using a mixed method approach, data was collected and analyzed to evaluate the effect lean six sigma has on the utilization of learning teams.

This research addresses issues with bringing advanced industry concepts such as LSS methodology into Freshman engineering classrooms head-on, by introducing these concepts just prior to the EDP lecture. This unique formula of instructor initiative, student collaboration and industry-based methodologies could serve as a catalyst for making the necessary improvements in the first year of a student's academic journey that has proven to positively impact engineering industrial interest, learning, recall and application.

With the goal of strengthening the engineering design lifecycle development pipeline, this proposed intervention for project-based learning, uses quantitative data points that track how well students are able to recall and apply Lean Six Sigma methodologies when faced with a design challenge. To assess how well instructor guidance and team interaction helped to motivate students and promote interest in hands on projects, a qualitative survey was administrated, in addition to the performance evaluation. To address these research questions, a sequential quantitative strategy was employed.

Fig. 3: Lego Mindstorms Robot used in team project by first-year students

Two instruments were utilized, (1) a familiarity and assessment questionnaire and (2) a demographic survey. Using Lego robots similar to the one pictured above, a fusion between technology and coding is developed, allowing for both technical and communication skills to mesh, when explored in a collaborative environment rich in scenarios that challenge student's critical thinking skills. Instructors can foster an environment that caters to peer interaction and instructor led engagement is optimal for experiential learning opportunities like the one proposed in this study.

Through active experimentation, students will benefit from the ability to learn, recall and apply Six Sigma tools along their journey towards becoming more familiar with the engineering design process. What began in industry can now be successfully translated to higher education using this approach. Using each phase of the Six Sigma lifecycle expressed via the DMAIC tool, students are equipped with the experimental tools necessary to properly access the current state of any engineering problem presented.

PARTICIPANTS AND DATA COLLECTION

During the Spring of 2024, 58 students of a physics-statics class were exposed to principles of Six-Lean Sigma with the purpose of introducing the Engineering Design Process via an industrial based learning approach. At the end of this intervention, 46 students answered a questionnaire that assessed their level of understanding of these principles and requested the level of familiarity of these principles prior to the intervention. After considering breaking down the data in demographic groups, a second survey requested information related to gender and ethnicity, but only 36 students answered this second survey. Table 2 shows the demographic information and the associated level of familiarity per demographic group. Majority students were classified as those students over-represented in engineering, White and Asian students while minority students those underrepresented, Hispanic, Black, and America-Indian.

	Gender		Ethnicity	
	1-Male	2-Female	1-Majority (White &Asian)	2-Minority (Hispanic, Black, American-Indian)
Familiarity				
0-Unfamiliar	12	6	8	10
1-Somewhat Familiar	8	4	8	4
2-Familiar	6	0	6	0
3-Very Familiar	0	0	0	0

Table 2. Demographic information of participants

To begin this study, students were given a pre-assessment to evaluate both knowledge and interest in the field of Lean Six Sigma as it relates to the Engineering Design Process. Questions related to previous teamwork experience as well as Python coding skills were also asked. Based on the feedback from the survey phase, teams of four students were established, considering content familiarity as part of the team dynamics. Instructions for the group project as well as lectures with relative content were administered prior to the start of the evaluation. With this project-focused initiative, a step-by- step approach towards improvement realization (San, 2016) that highlights the importance of DMAIC was emphasized through the creation of a problem and objective statement. Students were also exposed to tools that allowed them to analyze root cause and become proficient in determining the origin of issues that arise throughout the product design life cycle.

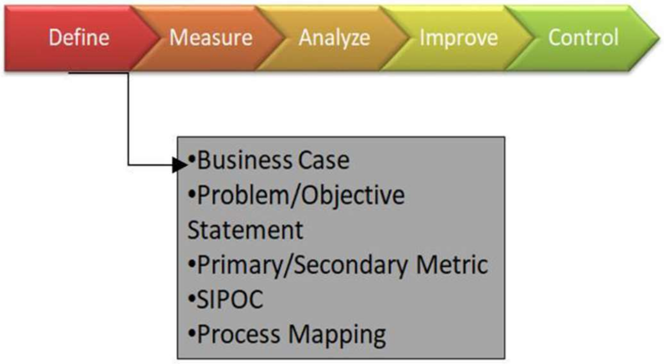

Fig. 3: DMAIC's Define Phase

With the understanding that process changes are directly influenced by the people involved, human and organizational change will be required throughout each phase of the Six Sigma lifecycle to be successful, hence the focus on both individual and team contributions at various stages of the project. A central principle of Total Quality Management is to avoid inspecting a product only at the end of a process (known as product control), but instead, promote monitoring of individual process steps to ensure that the process is running properly [9]. As part of the measuring phase, students must learn how to identify and define key performance indicators within Engineering.

To fully understand the extent to which the application of both experiential learning and social cognitive theories are effective, surveys were given to students at the initiation of the course to better understand their attitudes and apprehensions (if any) toward the engineering design phase and if they have any existing knowledge of Lean Six Sigma. Another survey was conducted with the same group of students at the end of the course to assess whether the Six Sigma methodologies used as part of the course development, increased their knowledge of the subject matter and the degree to which team collaborations assisted with that effort. The post-course survey evaluated to what degree knowledge was increased as a result of the student's engagement with the instructor and the guidance they provide with respect to various Lean Six Sigma and Engineering Design Phase related activities (courses, labs, peer mentors, industry speakers, etc.) throughout the semester.

RESULTS

To answer the first research question, and assuming non- parametric and ordinal-categorical data, the relationships between familiarity and scores was explored via a Spearman Rho ρ correlation. Table 2 shows a significant positive correlation meaning that students' growth in familiarity is matched with positive growth in the scores for their level of understanding after the intervention. The significant correlation however is only of 0.405 which for behavioral sciences is considered a small significant correlation.

To answer the second research question, the demographic survey correlated with the familiarity levels and scores resulting in the Table 3 data. These results show that as gender switches from Male to Female, there is no correlation with the scores, the level of familiarity decreases (ρ =-0.218) and as the ethnicity switches from majority group students to minority group students positively (ρ =0.0136)-meaning it increases as well.

	Spearman	
	ρ	p-value
Familiarity-Scores	0.405**	0.005

**p≤0.01

Table 3. Spearman Rho correlation for Familiarity and Scores (n=46)

As scores increase, familiarity also increases (ρ=0.327) but the relationship between scores and ethnicity is negative (ρ =-0.25) meaning that minority students score fewer points than their majority counterparts. The same occurs for familiarity and ethnicity, where the correlation is negative (ρ=-0.236) meaning that minority students are less familiar than their majority counterparts.

	Spearman	
	ρ	p-value
Gender-Scores	0	1
Gender-Familiarity	-0.218	0.20
Gender-Ethnicity	0.136	0.42
Score-Familiarity	0.327	0.05
Score-Ethnicity	-0.25	0.14
Familiarity-Ethnicity	-0.236	0.16

**p≤0.01

Table 4. Spearman Rho correlation for Gender, Ethnicity, Familiarity, and Scores (n=36)

DISCUSSION

Results show that the intervention highlighted in this research has the potential to greatly enhance student understanding through a direct match to familiarity with the subject matter being presented. Minority groups, including female students, are at a disadvantage in their familiarity with Lean Six Sigma and corresponding test scores covering similar topics. Research articles that focus on minorities in STEM are emerging, however, further interventions need to occur in order to open more industry-based opportunities for underrepresented groups.

Observations concerning the alignment between familiarity and an increase in scores with relatively significant correlation as a result of this intervention, highlight the significance of this research. These results demonstrate the potential the Lean Six Sigma classroom instructional approach can have on the improvement of teaching and learning as early as the first-year engineering experience.

In regards to the first research question proposed, it has been determined that as students become familiar with Lean Six Sigma, their performance scores improve. An intervention more attuned with the content of the first-year experience influenced by these principles has promising opportunities for future practice and research. These include (a) a more practical on-the-job situated experience, (b) a direct connection between abstract concepts and the practice of engineering, (c) increase in the number of students who are trained and certified as Lean Six Sigma analysts.

The second research question has implications that uphold the goals of broadening participation, with results showing how minority students are at disadvantage also in both areas observed (score and familiarity). Equipped with this information, instructors can lead early interventions to help facilitate inclusion of these groups (many of whom are enrolled in Community College learning environments) in the betterment of learning basic engineering concepts and its application for on-the-job situated experiences.

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