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Using Six Sigma to Improve Student Teamwork Experience and Academic Performance in Circuits Analysis Course

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Abstract

Recently, quality of teaching and learning has gained significant importance among Higher Education Institutes (HEI) stakeholders. Engineering education in many studies emphasizes the importance of using effective teaching strategies to enhance students' academic performance and students' satisfaction. These strategies help engineering educators in multiple ways, including creating a stimulating learning environment, actively involving students in the learning process, enhancing students' engagement, and improving students' learning. One of the most effective strategies includes utilizing collaborative teamwork. Many undergraduate Electrical and Computer engineering courses include teamwork activities. Group work can offer many benefits, including improving communication and teamwork skills, appreciation and respect for others. However, group work activity sometimes leads students into a challenging experience, especially for students who are not familiar with group activities at university, and may also decrease individual performance. When creating groups, instructors are faced with deciding whether to allow students to form their groups or assign them to groups, whether to switch groups or keep them the same all semester and whether to require students to submit their work individually or as a group. An Electrical Circuits course for major and non-major students is used as a case study. Six Sigma Methodology is implemented to investigate the issues related to students' teamwork experience. A Critical-to-Quality (CTQ) tree is constructed to identify the needs of the students. Potential causes are identified and analyzed using a Fish-bone diagram and 5-whys. Students' performance is used as a quality metric to evaluate the teamwork experience before and after the improvements. We collected students' academic performances based on four exams for more than 70 students over two academic years. New strategies to overcome students' teamwork challenges are identified. As a result, we redesign groups based on diversity in performance. The results show a significant improvement in the grades and teamwork overall performance as well as students' satisfaction. The control chart helped monitor the new implementation, and a standard procedure is designed to follow in other classes.

Introduction

Engineering education research has emphasized improving teaching practices to increase students' participation, retention, academic performances, and motivating students to pursue careers in STEM areas [1]. In the traditional teaching method, students learn the material through the lecture and ultimately show knowledge mastery through homework assignments and exams. This approach provides little opportunity for feedback during the learning process.

Teamwork has often been seen as a replacement or addition to traditional teaching approach in higher education. Students learn better when actively engaged in teamwork than in a traditional teaching approach. Recent research supports this observation, especially in STEM courses [2-7]. Also, educational research shows that in-class activity significantly impacts long-term material retention, critical thinking, communication skills, and increased class attendance [4,8-10].

Teamwork is an important part of any undergraduate engineering program. The Accreditation Board of Engineering and Technology (ABET) states that all ABET-accredited programs should give students: "An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives." [11]. Group work can offer many benefits, including improving communication and teamwork skills, appreciation and respect for others. However, group work activity sometimes leads students into a challenging experience, especially for students who are not familiar with group activities at university, and may also decrease individual performance. When creating groups, instructors are faced with deciding whether to allow students to form their groups or assign them to groups, whether to switch groups or keep them the same all semester and whether to require students to submit their work individually or as a group [12,13].

Instructors have the choice to use either student-selected group's form or instructor-assigned groups. Instructor assigned groups can be created randomly or through specific criteria to attempt to distribute student characteristics and group member resources. Instructors are also responsible for setting the lifetime of groups. They can choose to rotate groups during the semester to ensure that students can work with people of different abilities and backgrounds or keep the same group for the whole semester.

Six Sigma (SS) is a tool that can be used to enhance the quality of education [14]. Effective quality management is built on a foundational concept called customer focus in Six Sigma methodology. Identifying customers and understanding their expectations is fundamental to achieving customer satisfaction. In our project, the customers are the students, and the education and learning experience is the service they need. In another aspect, the students' future employers are the customers and the students, in this case, are the products that need to be delivered to the employer. One of the main goals to universities is to provide high-quality education and learning experience to students that enable students and prepare graduates to serve the community [15,16].

Many studies were conducted to improve the Higher Education Institutes (HEIs) education process using Six Sigma, but only a few applied the methodology in actual cases. Six Sigma and Lean Six Sigma (LSS) were implemented to improve classroom performance and reduce defects. Defects in these studies are the students' final grades [17, 18]. LSS was also applied to increase admissions [19] and passing rate [20]. In [21], SS was used to improve the learning outcomes, the Voice of customers (VOC) was collected by interviews and analyzed to identify students' needs. The study included the four most important American Society for Quality (ASQ) leadership competencies [22]. It noted from the previous studies that Six Sigma is a powerful process improvement methodology in educational institutions.

In this paper, we used Six Sigma Methodology to improve students' teamwork performance and overall class performance in one engineering course. The study explores the effect of group work activities to predict students' academic performances. We investigate the issues related to students' teamwork experience using quality management tools. Finally, we present the results that show a significant improvement in the exam grades and overall teamwork performance as well as students' satisfaction.

Circuits Analysis Course Description

At the University of Georgia, Circuits Analysis course is a required, high-enrollment, high-impact course in engineering disciplines. The course is designed to serve the purpose of educating an engineering student about the fundamental behavior of the five basic individual active and passive circuit elements, and the basic concepts and laws that govern their group behavior when these individual circuit elements are connected in a circuit or a system. University of Georgia students take Electrical Circuits in a compressed, one-semester three hours format, with classes meeting for two 50-minute periods and two hours lab session each week. The format dictates a faster-than-usual pace of coverage of the material with little time spent reviewing course material from previous lectures.

During the semester, Students will have three exams to test their knowledge and understanding of the subject. Each exam designed to be closed-book, closed notes, open-mind with two side formula sheet. Exam1 covers the concepts of analyze DC circuits using ohms law, Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL). Exam2 covers the concepts of analyze DC circuits using circuits analysis methods and theorems such as nodal analysis, mesh analysis, Superposition principle, and Thevenin and Norton theorems. Exam3 covers the concepts of analyze steady state AC circuits using ohms law, Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL), circuits analysis methods and theorems such as nodal analysis, mesh analysis, Superposition principle, and Thevenin and Norton theorems. Final exam is a three hours comprehensive exam covers the concepts in exams 1,2 and 3 and concepts of analyze steady state AC with Ideal Transformer, AC power calculation and analyze first and second order circuits.

Each exam was supported by 4-5 in class group assignments and 1-2 practice problem sets with solution, immediate feedback was used with the following features:

- The video was assigned before each class.
- Concept Quizzes were incorporated with each video to encourage students to watch the video and test their understanding of it. Students only received points on these questions if they answered them correctly.
- Mini-lectures that presented material prior to in-class assignment questions were used throughout the lecture to identify if students were grasping the main concepts of the lecture.
- In-class assignment questions aimed to challenge deep understanding.
- Online feedback system used to collect student answer to each in-class assignment questions.
- Students initially had 10-15 minutes to answer each question in the in-class assignment individually. The correct answer was hidden from the students.

- Discussed the question as group for 5-7 minutes and were expected to come to a consensus before answering again.
- Then students answered the same in-class assignment question again, allowing them to change their answers based on the discussion. The grade for the in-class assignments will be based on the group work using the Top hat as student's response system using in the class. In general, most of the class time used for group work.

Methodology and Results

This study aims to improve the students' grades and improve the whole learning experience, including in-class group work experience. Six Sigma is a data-driven quality strategy used to improve processes. It has five phases: Define, Measure, Analyze, Improve, and Control (DMAIC). The letters in the acronym represent the five phases that make up the process, including the tools to use to complete those phases. The first step was to rewrite the Six Sigma phases to reflect the higher educational process (Figure 1).

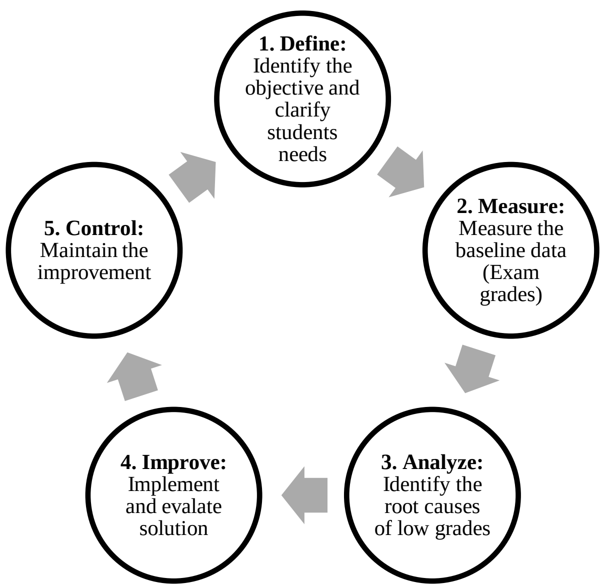

Figure 1: DMAIC process for Educational applications

1. Define

In the first phase we need to identify the problem and understand students' needs. It is observed that many students have got less than the pass mark (60%) in exams. Identifying the students' needs is essential in this step, so the Voice of Customer (VOC) is collected. In general, VOC is the component of customer experience that focuses on customer needs, wants, expectations and preferences. Course evaluation and surveys are used to collect VOC data and information. CTQ tree illustrates the students' needs, the drivers of the need, and the requirements to fulfill this need (Figure 2). The main student need is identified as; improving students' performance in exams since exams grades are performance metrics that reflect the student's understanding.

2. Measure

The second phase in the DMAIC process is Measure. After identifying the problem and the opportunity to improve, we need to quantify the problem and measure the pre-improvement performance. The baseline data is used to find the Defect per million opportunities (DPMO), a quality metric representing the number of defects per million potential defects. DPMO is calculated as follows:

$$\text{DPMO} = \frac{\text{Number of actual defects}}{\text{Number of defect opportunities}} \times 1{,}000{,}000$$

Statistically, the six sigma goal is to have 3.4 DPMO or less. To calculate the DPMO for the student's grades, we assumed that every grade lower than 60% in any exam is a defect. The exams included in the calculations are exam 1, exam 2, exam 3, and the final exam. Before each exam, the students were given practice examples, and teamwork was required for solving the in-class assignments.

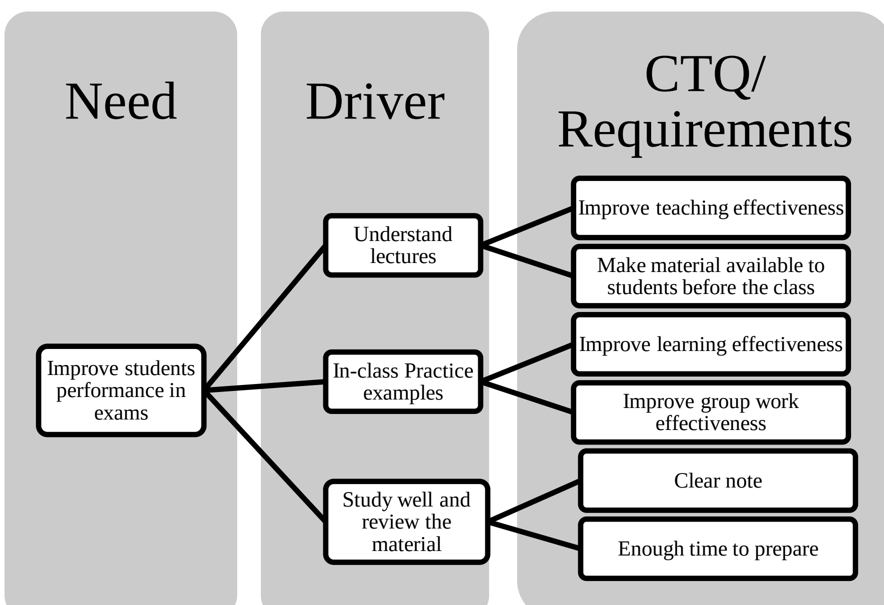

Figure 2: CTQ tree for students performance on exams

The DMPO and Sigma level calculations are shown in table 1

Table 1: Measurement phase calculation summary (DPMO before the improvements)

Before improvement	**Values**
Number of students	35
Number of exams	4
Number of defects opportunities	35 x 4 = 140
Number of actual defects*	40
DPMO	40/140 x 1 million = 285,714 DPMO
Sigma level	2.07 sigma

*Note that the number of the actual defects are the number of exams with score 60 or less.

Each exam was supported by 4-5 in-class group assignments and 1-2 practice problem sets with the solution and the poor performance is not equally distributed across exams because over the semester, the course material gets harder and thus, exams get harder too. Figure 3 shows the distribution of the exam2 scores for self – selected group and proposed group selection technigue.

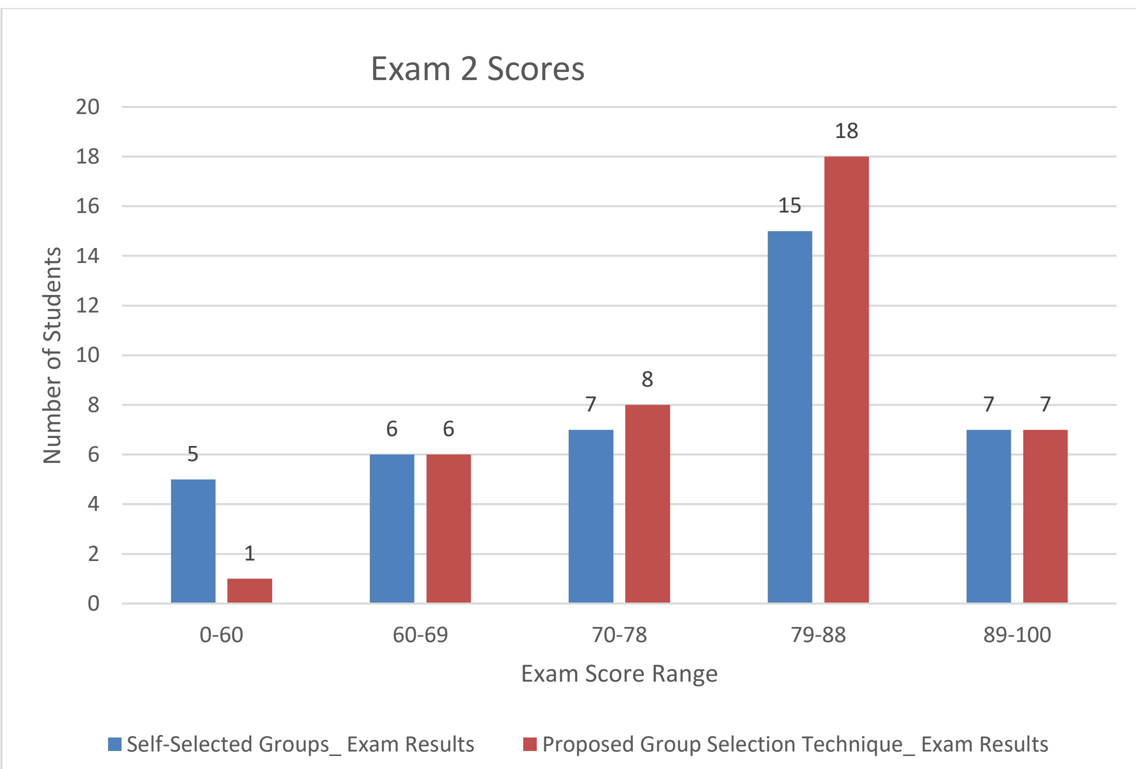

Figure 3: Exam 2 scores

3. Analyze

Analyze stage used to analyze the process to determine root causes of variation and poor performance (defects). The 5- whys is a basic root cause analysis technique used to identify the root cause of the high variation and low students grades (Figure 4). The course is designed to have weekly in-class activities that allow students to work in teams, exchange information, and check their understanding. The students were asked to form their groups. It is noticed that students work with the same group every week and work with their friends. This situation creates an issue that students don't exchange information effectively and spend more time to complete group assignments. It also noted that self-selected groups of friends might spend more time off task discussing extracurricular issues [23].

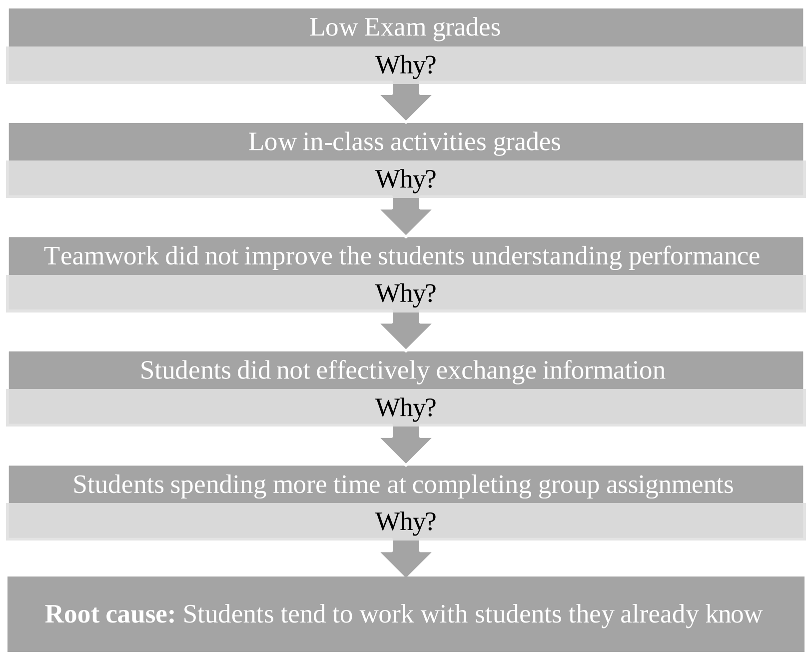

Figure 4: 5 Whys analysis

4. Improve

The main goal of the Improve phase is to solve the root cause and verify improvements. The results and observations show that self-selected groups technique is not effective in groupwork since students choose a close friend to work with or the group formed based on whom the student happened to be sitting next to on the first day of class. Student-selected groups resulted in most of the students remaining in the same group for the entire semester. Also, we noticed that the students who worked in the same group ended up they have almost the same final grade on the course. So, brainstorming sessions were held to generate and evaluate solutions. As a result, the group selection technique was implemented as follows: Form groups based on students' performance. Each group has three students from all performance levels (Above the average, around the average, and below the average). After each exam, the members are rotated, and groups adjusted based on students' performance on these exams.

Defects per million oppurtinities and Sigma Levels were calculated to verify the improvements. Results show an improvement in the sigma level:
The DMPO and Sigma level calculations are shown in table (2).

Table 2: Improve phase calculation summary

After improvement	**Values**
Number of students	42
Number of exams	4
Number of defects opportunities	42 x 4 = 168
Number of actual defects*	28
DPMO	28/168 x 1 million = 285,714 DPMO
Sigma level	2.47 sigma

The results imply that the number of low-performance exam scores is reduced from 40 to 28 even though the total number of exams was increased from 140 to 168. One of the six sigma quality metrics to show the improvement in numbers is the sigma level. Our data show that the sigma level has improved from 2.07 to 2.47. This improvement means that the number of students who scored less than 60 in exams reduced from 285,714 per million opportunities to 166,666.7 per million opportunities.

Results mainly show an increase in exam scores of average and below-average students (Figure 3). However, a slight increase in exam scores of the above-average students. These results indicate that the proposed group-selection method benefited mostly below-average and average students. The student that needs help benefits from individualized attention. But above the average student also benefits. To explain a concept clearly, you have to understand it clearly, and in the process of explaining it, you can gain new insight. Students' feedback was collected informally and data shows that students like the experience and appreciate the opportunity of working in different groups.

5. Control

The fifth and last phase is to control and maintain the improved process. A control plan has been developed to ensure the new process of group work selection is maintained. Further improvements and adjustments will be identified in the future for a continuous improvement process. In addition, C-chart will be used to monitor the students' performance and track the sigma level of the students' grades. The value of the current sigma level is around 2.5 which is relatively low compared to the common six sigma value in manufacturing and other services application. Note that there is no specific value recommended for higher education. Improving students' grades is complicated compared to improving the quality of products or processes. In education, the quality of the lectures, examples, group work are not the only factors that may affect the students' grades. Many factors that could significantly affect the students' performance are uncontrollable and unmanaged by the instructor. For example, students' absences and student personal issues are common unmanaged reasons that could cause low performance in exams. This study focused on improving the sigma level and reducing the number of low-performance exams. More improvements might be needed in the future to increase the sigma level value further and improve the overall students' performance. More research and case studies are required in order to find out what sigma level is good in higher education.

Conclusions

This study demonstrated the application of the Six Sigma methodology to improve students' teamwork experience and academic performance in circuits analysis course. The study assures that the use of the six sigma approach is applicable in education systems.

When instructors select group members based on students' performance, students are more likely to benefit from the group work through exchanging information, discussing, and helping each other understand the problem and solution procedure. Then, rotate groups after each exam based on students' performance on these exams to solve the in-class activities and keep the diversity of each group.

Lessons learned from this project include; Six Sigma, a powerful tool that helps instructors understand the teaching process, students' needs, and opportunities to improve. Following the DMAIC process helps make scientific decisions based on facts and data in addition to experience and previous research.

The case study also proves that the quality of group work has a significant impact on students' performance. Designing group work activities is not enough to improve the students' experience and performance. The selection of the group members is essential, and decisions should consider the course subject, students' needs, and previous experience.

In the future, more CTQ requirements will be investigated, and more improvements will take place, to enhance the students learning experience, exam performance, and overall course performance. This project considers only one course over two academic years for undergraduate students. Hence the outcomes cannot be generalized to all majors or students. However, the results could provide valuable insights to improve the learning outcomes of high education institutions.

References

[1] S. Singer and K. A. Smith, "Discipline-based education research: Understanding and improving learning in undergraduate science and engineering," pp. 468–471, 2013.

[2] R. R. Hake, "Interactive-engagement versus traditional methods: A sixthousand-student survey of mechanics test data for introductory physics courses," American journal of Physics, vol. 66, no. 1, pp. 64–74, 1998.

[3] C. H. Crouch and E. Mazur, "Peer instruction: Ten years of experience and results," American journal of physics, vol. 69, no. 9, pp. 970–977, 2001.

[4] L. Deslauriers, E. Schelew, and C. Wieman, "Improved learning in a large-enrollment physics class," science, vol. 332, no. 6031, pp. 862– 864, 2011.

[5] S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth, "Active learning increases student performance in science, engineering, and mathematics," Proceedings of the national academy of sciences, vol. 111, no. 23, pp. 8410–8415, 2014.

[6] J. M. Fraser, A. L. Timan, K. Miller, J. E. Dowd, L. Tucker, and E. Mazur, "Teaching and physics education research: bridging the gap," Reports on Progress in Physics, vol. 77, no. 3, p. 032401, 2014.

[7] L. Deslauriers and C. Wieman, "Learning and retention of quantum concepts with different teaching methods," Physical review special topics-physics education research, vol. 7, no. 1, p. 010101, 2011.

[8] W. K. Adams, K. K. Perkins, N. S. Podolefsky, M. Dubson, N. D. Finkelstein, and C. E. Wieman, "New instrument for measuring student beliefs about physics and learning physics: The colorado learning attitudes about science survey," Physical review special topics-physics education research, vol. 2, no. 1, p. 010101, 2006.

[9] E. Brewe, L. Kramer, and G. OBrien, "Modeling instruction: Positive attitudinal shifts in introductory physics measured with class," Physical Review Special Topics-Physics Education Research, vol. 5, no. 1, p. 013102, 2009.

[10] J. Watkins and E. Mazur, "Retaining students in science, technology, engineering, and mathematics (stem) majors," Journal of College Science Teaching, vol. 42, no. 5, pp. 36–41, 2013.

[11] A. ABET, "policy and procedure manual (appm), 2019–2020," 2019.

[12] A. Danowitz, "Group work versus informal collaborations: Student perspectives," in 2017 Pacific Southwest Section Meeting Proceedings, 2017.

[13] K. A. Smith, "Cooperative learning: Effective teamwork for engineering classrooms," in Proceedings frontiers in education 1995 25th annual conference. Engineering Education for the 21st Century, vol. 1. IEEE, 1995, pp. 2b5–13.

[14] A.-P. Pavel et al., "The importance of quality in higher education in an increasingly knowledge-driven society," International Journal of Academic Research in Accounting, Finance and Management Sciences, vol. 2, no. Special 1, pp. 120–127, 2012.

[15] D. Kremcheeva and E. Kremcheev, "Implementation of the six sigma method in the educational process," in Journal of Physics: Conference Series, vol. 1384, no. 1. IOP Publishing, 2019, p. 012022.

[16] S. Paramasivam and K. Muthusamy, "Study of critical success factors in engineering education curriculum development using six-sigma methodology," Procedia-Social and Behavioral Sciences, vol. 56, pp. 652–661, 2012.

[17] M. G. Kanakana, J. H. Pretorius, and B. J. van Wyk, "Applying lean six sigma in engineering education at tshwane university of technology," in Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management, 2012, pp. 211–220.

[18] R. K. B. Navas, R. Akash, G. Sathish, and J. M. Azharudeen, "Six sigma in education: Examination result analysis using six sigma-a case study," in 2016 IEEE 4th International Conference on MOOCs, Innovation and Technology in Education (MITE). IEEE, 2016, pp. 245–250.

[19] C. Laux, N. Li, C. Seliger, and J. Springer, "Impacting big data analytics in higher education through six sigma techniques," International Journal of Productivity and Performance Management, 2017.

[20] S. Tenali, R. S. Ganti, and K. Taranikanth, "Implementing lean six sigma to improve the ratio of admissions to placements in an academic year: statistical and psychological case study of a technical institute," in 2015 International Conference on Industrial Engineering and Operations Management (IEOM). IEEE, 2015, pp. 1–12.

[21] G. A. Tetteh, "Improving learning outcome using six sigma methodology," Journal of International Education in Business, 2015.

[22] K.-T. Yu and R.-G. Ueng, "Enhancing teaching effectiveness by using the six-sigma dmaic model," Assessment & Evaluation in Higher Education, vol. 37, no. 8, pp. 949–961, 2012.

[23] Hassaskhah, Jaleh, and Hamideh Mozaffari. "The Impact of Group Formation Method (Student-selected vs. Teacher-assigned) on Group Dynamics and Group Outcome in EFL Creative Writing." Journal of Language Teaching & Research 6.1, 2015