

Applying Lean Six Sigma in Engineering Education at Tshwane University of Technology

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Abstract

Since the implementation of Lean Six Sigma in higher education is not widely spread, this paper illustrates how Lean Six Sigma can be effectively applied to engineering education. The results of this paper indicate that students spend less time on their subjects during normal lecturing weeks than the time they do on their work during test weeks; therefore there is a need to increase student engagement during normal lecturing weeks. Group work and E-learning has been proposed as a solution for student engagement. The standardization of this solution has been proposed as a control measure to sustain the improvements. Implementation of the proposed solution increased the throughput of one of the subjects from 38% in 2009 to 71% in 2010.

Keywords

Six Sigma, throughput, engineering education

1. Introduction

The revised Higher Education Act (South Africa 1997b) set the scene to redesign the demography of higher education. This has resulted in the development of the National Plan for Higher Education in South Africa which serves as a framework for the transformation and reconciliation of higher education institutions. The key objectives of the National Plan for Higher Education in South Africa are to increase access, equity, diversity, research capacity, and to reorganize the institutional landscape. To achieve the objectives of this plan (2001), all 36 higher education institutions were merged into 22; in certain cases, institutions that were previously disadvantaged merged with those that were previously advantaged. The merger resulted in the formation of Universities of Technology in 2004. The five universities of technology (UoTs) that were created are: Tshwane University of Technology, Durban University of Technology, Cape Peninsula University of Technology, Vaal University of Technology and Central University of Technology [1]. According to [2], in South Africa, the ratio of engineers is 473 per million citizens, which is far lower than that of other developing countries such as, among others, Chile and Malaysia, where the ratio is 14600 and 1843 per million citizens respectively. Hence, it is evident that the skills capacity in South Africa is low [3]. The skills shortage of technicians and technologists was recently reported by the government. Since the issue of good technicians and technologists leaving the country has recently surfaced, the UoTs are being challenged to produce more graduates [3]. The longstanding problem of the low throughput ratio of such students in UoTs as well as the pressure, which the country is currently facing owing to the lack of such graduates forces the UoTs to find a new way to deal with the throughput problem.

Scott et al. [2] reveal that from 2000 to 2004 the national average throughput rate of engineering students attending UoTs (formerly known as Technikons) was 23 percent after 5 years for a three year National Diploma. This is very low for a developing country that is experiencing a skills shortage. It is evident that throughput is a major concern for all UoTs in South Africa; therefore action has to be taken to address this problem. Higher education institutions

cannot afford to merely wait for this problem to disappear; it is imperative that they find ways to solve it. Some of the tools that have already been utilized by industry could be employed to do so. Tools like Lean Six Sigma, which are designed to eliminate waste, could be applied to the educational processes at UoTs.

2. Methodology

The Define, Measure, Analyze, Improve and Control (DMAIC) methodology was applied in the following manner in order to address the problem: In the define phase, the project team was formed by selecting key personnel. Subsequently, the problem statement was developed using historical data. The project was developed and each member of the team ensured that the process owner understood the scope of work and agreed to it. In the measure phase the measurement system analysis was performed, which proved to be valid. The team made decisions regarding the data to be collected, whereupon the data collection instrument was developed and used accordingly to collect the data. Thus, the project matrix was developed. Quality tools were employed to determine the root cause of the problem. Discrete Statistics were used to analyze collected data such as the Normality test, two sample T test and box plots. The team then suggested solutions to the problem and the implementation took place thereafter. The team implemented control measures to ensure that the improvements remain intact once the project has been completed. Subsequently, they handed over to the process owner. Data from the Faculty of Engineering and the Built Environment was used throughout the project, that is, historical data and the data that had been collected during the project.

3. Analysis and Results

Lean Six Sigma is a combination of Lean Manufacturing and Six Sigma techniques employed to reduce process variation and to improve an organization's bottom line. The term "lean" focuses on solving simple, minor problems which require common sense to resolve. Tools such as the Value Stream Map and Seven Wastes are employed to identify and eliminate waste[4]. Six Sigma, on the other hand, is defined both in business and statistical terms. In business terms, Six Sigma refers to a business improvement strategy employed to improve profitability, the effectiveness and efficiency of all operations, and to minimize waste[5]. In statistical terms, Six Sigma refers to 3.4 defects per million opportunities (DPMO), where the term sigma represents the variation in the process[6]. Figure 1 illustrates the relationship between DPMO and Sigma: that is, a DPMO yield of 0.001 has a short term sigma capability of Six Sigma, while a process with a DPMO of 1350 has a short term sigma capability of a three Sigma.

3.1 Application of Lean Six Sigma framework in education

Lean Six Sigma methodology contains the same steps as the traditional Six Sigma steps (DMAIC), where each of the DMAIC phases are in turn broken down into two steps. For each step, a list of deliverables is defined. Lean analysis tools and standard improvement models are imbedded in this project approach. The following Lean Six Sigma phases are outlined below [7].

3.1.1 Define phase – project definition

This phase guides a team to define the problem effectively, correctly identify the problem and to justify the commitment of expenses and resources so as to achieve maximum returns. Establishing the customers' needs and requirements; prioritizing problems, activities and resources; identifying opportunities for improvement and projecting goals, objectives and milestones are core outputs of the said phase[8]. Various tools are used during this phase to ensure that the scope of the project and the problem are adequately defined[9], namely, Pareto analysis, process flowcharts, project charter value stream mapping, and 5s. In this project, the following problem statement was developed from the guidelines outlined above. Data relating to the problem formulation was based on first time students entering the University from 2004 to 2009. The study was carried out utilizing the historical data. The students were traced until graduation and a sample was used to calculate the sigma level and current throughput rate. The problem statement formulated by the team follows: The current throughput rate for the Faculty of Engineering and Built Environment at TUT is $\leq 23\%$, which, as mentioned, is very low for a developing country. The faculty aims to improve the throughput to at least 50% by the end of 2011.

3.1.2 Measure phase – define CTQs and validate the measurement procedure

The measure phase focuses on the collection of data related to the problem statement. It is imperative that appropriate data is collected accurately to ensure the validity thereof. A tool such as the measurement system analysis (MSA) can be used in the measure phase to ensure accuracy. Critical costs to quality (CTQ) are also identified and the process inputs and outputs are measured. The process baseline is established and each process is

measured in order to monitor its performance, thus identifying opportunities for improvement. The intended output of this phase is the baseline sigma level. The data can be used during the analysis phase to validate the causes of the problems. Institutional data obtained from the institution's data warehouse was used to develop the baseline sigma level. Due to the fact that the data was not in the form desired for analysis, a measurement system analysis was applied in order to validate the data that was collected so that it could be used for statistical purposes[8]. The results of the measurement system analysis are depicted below.

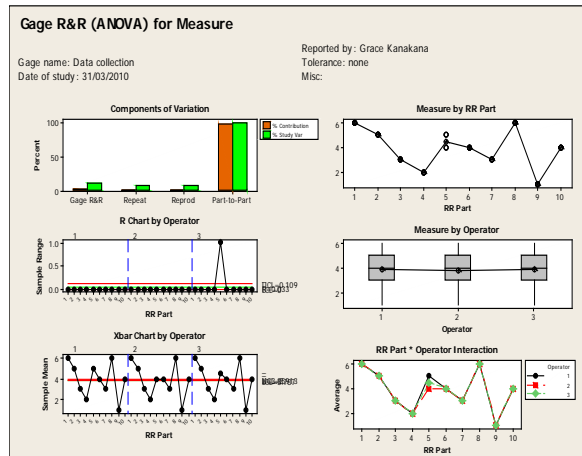


Figure 2: Gage R & R for data collection

A variable Gage R&R was conducted in order to ensure that the team members collecting the data knew which data to collect and that they would do so accurately and reliably. The importance of accurate data collection is emphasized since the accuracy of the analysis relies on the accuracy of the collected data. The input determines the output. The results drawn from the analysis revealed that there is a minimal contribution due to the R&R Part which suggests that our data collectors measured the data given to them in the same manner. The results also demonstrate that they reported very similar readings. Since the Measure by Operator graph is almost straight, it validates the view that the data collectors are on the same level in terms of reading the data.

The R&R Part* Operator interaction indicates whether any given data sheet was difficult to read by any particular data collector. In the graph above it is evident that document 5 was difficult to read since most data collectors recorded errors with regards to that document. This information allows the researcher to review the document in order to ensure accurate data collection. Since the study had validated the data collected, the team gathered additional data which was used to determine the baseline sigma level as well as to show the relationship between the Z value and the sigma level. Data collection will continue until the projects end. Six Sigma requires a constant analysis of data in order to improve the process[10].

In the study, it was found that 1005 of 2348 students failed to graduate within 6 years after entering the engineering faculty. This resulted in a sigma level of 1.3 which is very low in comparison with international universities, which are normally positioned at 3 sigma levels. It is important to note that the sigma level is calculated using the following formula: The defects per million opportunities (DPMO) are equal to defects divided by the number of opportunities plus a 1.5 sigma capability shift.

$$DPMO = (\text{Defects}/\text{Opportunity}) * 10000, \text{Sigma level} = \text{NORMSINV}(1 - (\text{Defects}/\text{Opportunity})) + 1.5$$

The objective of the project is to improve the sigma level from 1.6 to at least 3 sigma, thereby improving the throughput in terms of the above figures. The fundamental metrics of Six Sigma will be applicable to the problem, which is used during the study. The following items represent the nomenclature and relationships that apply to Six Sigma, with modifications to fit the application to the engineering education process.

Defects (D) – all the factors affecting the faculty throughput rate entail various aspects, from students not meeting the minimum assessment requirements to the infrastructure contributing to the students' success.

Units (U) – the number of students who entered the engineering faculty in 2004 constitute the sample of this study.

Opportunity (O): Any engineering process for which there is a possibility of affecting the throughput rate.
 Defects per unit (DPU): defects /units.

Yield (Y) – represents the Poisson distribution, which equates to the probability of zero defects. Mathematically, this relationship is

$$\begin{aligned}
 (1) \quad Y &= P(x = 0) = \frac{e^{-\mu}}{x!} = e^{-\mu} \\
 (2) \quad &= e^{-\frac{D}{U}} = e^{-DPU}
 \end{aligned}$$

where μ is the mean of the distribution and x is the number of failures: if 1005 defects were identified, then the number of defects per units is 1005/2348, and the defects per units (DPU) is 0.43. The probability of obtaining zero defects (yield) is

$$\begin{aligned}
 &= e^{-\frac{D}{U}} = e^{-0.43} \\
 &= 0.6505
 \end{aligned} \tag{3}$$

The Poisson distribution can be used to estimate the Z variable equivalent. The Z equivalent can be determined by using DPU from the normal distribution table, and if a 1.5 shift is factored in, the sigma value can also be calculated.

A DPU value of 0.43 results in a Z value of 0.18 and, using a normal distribution table with Z transformation, the sigma level value is 1.68.

$$\text{Throughput yield: } Y_{TP} = e^{-\frac{D}{U}} \tag{4}$$

In order to improve the faculty throughput, the critical cost to quality must be identified, the variations impacting these processes must be identified and measured constantly in order to improve. For this study, the following variables were found to exert a direct impact on the faculty throughput in the Department of Industrial Engineering.

The following matrixes were developed for this problem:

$$Y = f(x_1, x_2, x_3 \dots \dots \dots etc) \tag{5}$$

Where Y = Throughput rate and $x_1, x_2, \dots \dots \dots etc.$ are variations in the process.

For this problem, the following variables that contribute directly to throughput rate were selected: $x_1 = \text{student's subject failure}$ and $x_2 = \text{students drop out}$. These variables will be analyzed and improvements will be made in order to reduce the variation in the process.

3.1.3 Analyze phase – diagnose the current process and identify potential influence factors

This phase uses the observations and collected data to pinpoint and verify the causes of variation and waste. The tools to be utilized in this phase are: the Cause and effect diagram, Kaizens, Pokeyoke, SMED, Hypothesis, Correlation, Anova, Regression analysis and other statistical tools[4].

The Pareto analysis method is used to identify the defects that are more important to increasing throughput. Pareto analysis uses the 80, 20 principles. The analysis says that only 20% of the defects contribute to 80% of the low throughput. In the table below, the students who fail subjects and dropout contribute to 96% of the throughput. If the faculty can find a way to improve the subject's failure rate and reduce the number of dropouts, the throughput will increase significantly.

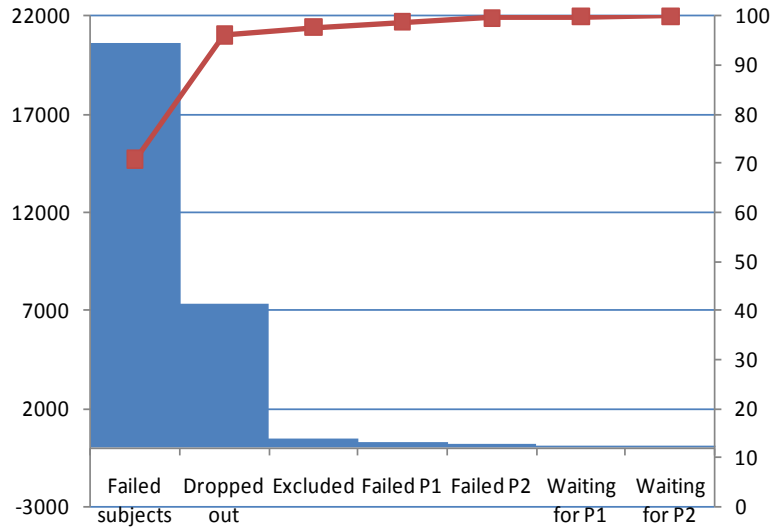


Figure 4: Pareto Analysis Graph

For this study, we focused on student subject failure as it contributed 71% towards the low throughput, according to the Pareto analysis. In order to do this effectively, we needed to scope the project further. In the faculty, there are 2718 subjects, which are offered per semester. To narrow down the subjects, the need to look at areas of influence was imperative, therefore the team decided to utilize the Industrial Engineering Department for this study, because the lead researcher is the acting Head of Department. This would enable the team to implement the necessary changes with ease as well monitor the results. The Industrial Engineering Department offers 26 subjects, of which the team needed to determine those that have a low throughput rate. Utilizing 2007 to 2009 data, the graph below indicates 5 subjects with the lowest throughput rate from 2007 to 2010. The team decided to focus on QAS201T, since it was the one with the lowest throughput rate.

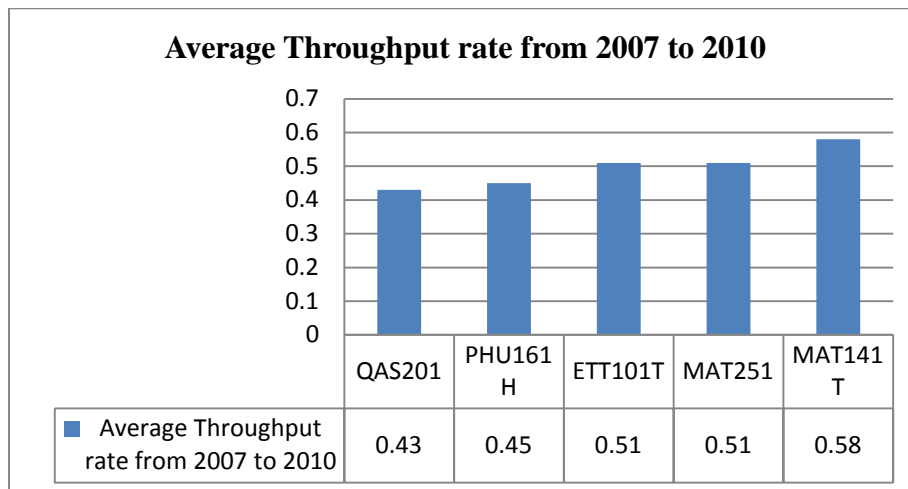


Figure 5: Throughput rate graph for 5 bottleneck subjects

The next phase of Lean Six Sigma was to determine why students were failing the subject QAS201T. In order to determine the root cause of this phenomenon, a team of QAS201T students was formed to analyze why the students fail the subjects. An additional team of lecturers from the industrial engineering department was formed to work together to determine why students were failing QAS201T.

In order to ascertain the root cause of the failure rate of QAS201T, the cause and effect analysis tools were used. [4] asserts that in order to develop a cause and effect analysis effectively, a 5 why analysis must be performed. With this method, team members must ask themselves ‘why’ 5 times in order to determine the root cause of the problem. Using the diagram below, the team identified 5 causes of students failing the subjects and alternatively dropping out of the program.

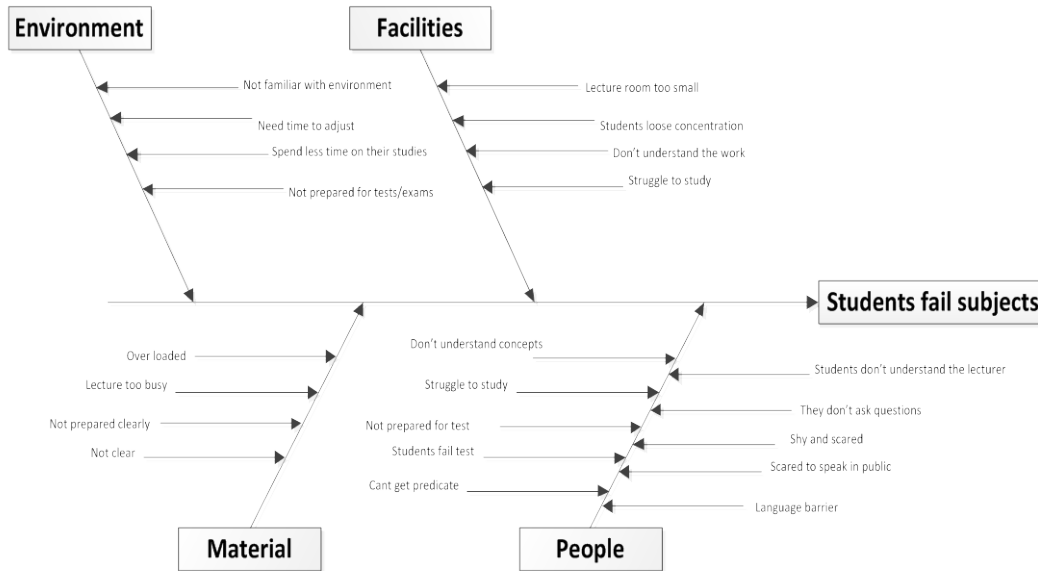


Figure 6: Cause and effect diagram

Based on the diagram above, the team voted with regards to the causes they think affect the students failing the subject. The following list was identified:

- Students fail the tests
- Students struggle to study.

The cause and effect analysis helped to identify possible causes of the failure. Subsequently, the team needed to contextualize the impact of these elements on the students failing the subject. In order to test these causes, a survey was conducted with the students as the respondents. They were asked to indicate to what level the items above contribute to students failing the subjects.

Students fail tests as a cause for students failing subjects: the TUT requirements stipulate that students need to attain at least 40% in order to pass that particular subject test. Normally, written tests weigh more than tutorials and assignments, since this is the only way to test a student’s cognition level for that particular subject matter. In order to test this cause, we sampled the student’s performance and the data collected clearly indicates that the students who fail tests but somehow gain examination entrance, fail the examination. Hence, this particular phenomenon was verified as a cause. Students struggling to study were identified as the second cause of student subject failure. Historically, students are required to study teaching and learning material in the form of text books, modules and notes in order to pass their assessments. Failure to study in most cases leads to students failing the subject. In order for the team to test this cause, a focus group was formed to test the following hypothesis.

A: students who studied

B: students who didn’t study

The hypothesis statement is as follows: the performance of students who study is equal to the performance of students who do not study their course material.

H0: Mean Test results A = Mean of test results B

H1: Mean Test results A ≠ Mean of test results B

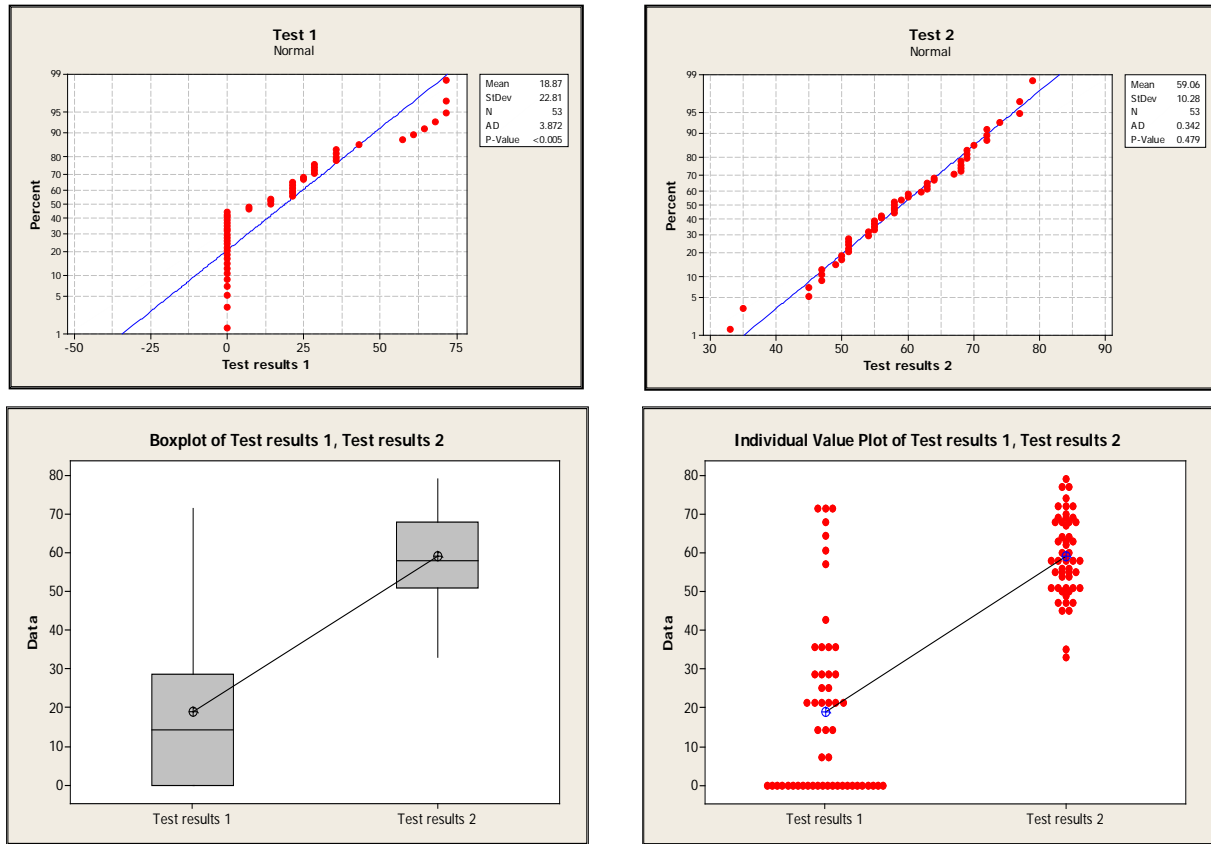


Figure 7: Normality tests and Box Plots test for Test1 and Test 2 data

A two sample t test was utilized for this study, which is suitable because it tests the equality of means of two subgroups. Two-sample t test Results;

	N	Mean	StDev	SE	Mean
Test results 1	53	18.9	22.8	3.1	
Test results 2	53	59.1	10.3	1.4	

Difference = μ (Test results 1) - μ (Test results 2)

Estimate for difference: -40.19

95% CI for difference: (-47.00, -33.37)

T-Test of difference = 0 (vs not =): T-Value = -11.70 P-Value = 0.000 DF = 104

Both use Pooled StDev = 17.689

The P value results for this analysis is $P = 0.000$; it is less than 0.05, therefore we reject the null hypothesis. Therefore the test results of students who study are not equal to the test results of the students who did not study. The results validate that students need time to study in order for them to pass tests or exams; it is therefore important for us to ensure that students engage with their work.

To understand the current situation, the team decided to determine how much time students spend per week studying the subject called Quality Assurance 2 (QAS201T) when they write a semester test or during a semester test week, and after the semester test week. In this regard, hypothesis testing was performed utilizing two sample t tests.

The hypothesis statements are the following:

The time spent studying the subject QAS201T during a test week is equal to time spent studying QAS201T during a normal lecturing week.

H0: Mean time spent studying during test week = Mean time spent studying during normal classes.

H1: Mean time spent studying during test week \neq Mean time spent studying during normal classes.

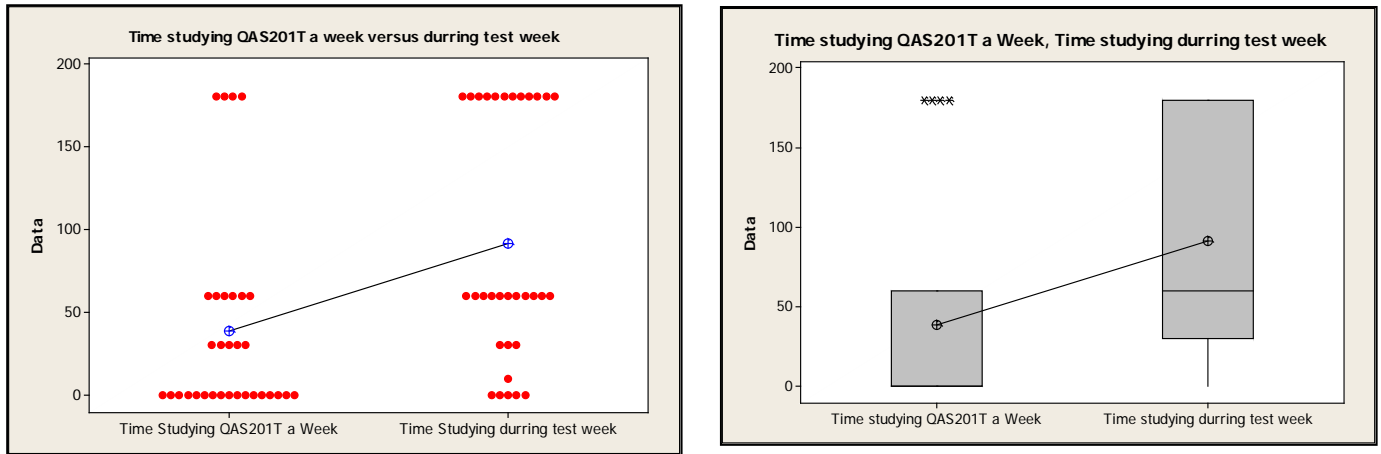


Figure 8 and 9: Individual value plots and box plots for 2 sample t test results of time spent studying QAS201T

Two-sample T for Time studying QAS201T a Week vs Time studying during test week.

	N	Mean	StDev	SE Mean
Time studying QAS201T per week	32	38.4	59.1	10
Time studying during test week	32	91.3	72.9	13

Difference = μ (Time studying QAS201T a Week) - μ (Time studying during test week)
 Estimate for difference: -52.8
 95% CI for difference: (-86.0, -19.6)
 T-Test of difference = 0 (vs not =): T-Value = -3.18 P-Value = 0.002 DF = 59

The p-value for this study is 0.002, which is below 0.05; therefore we reject the null hypothesis and accept the alternative. The results indicate that the average time students spend on QAS201T during normal classes is less than the average time they spend studying this subject during a test week. These results indicate that on average students spend 38 minutes studying QAS201T per week as opposed to 91 minutes during a test week. The results also indicate that most students study during the semester test week. During normal classes, very few students study their work, hence the feeling of not having sufficient time to prepare for the test.

This validates the fact that student engagement with their work is important for them to pass the subjects. It also indicates that if the throughput of QAS201T is to be improved, there must be an increase of the amount of time that students spend studying the subject per week during normal lecturing time. The results of this test prove that if student struggles to study and lecturers use traditional methods of teaching and learning, students will fail the subject. Occasionally, this might even lead to students dropping out. It was very clear that this intervention is a life line of knowledge acquisition.

3.1.4 Improve phase – establish the effect of the influential factors and design improvement actions

This phase enables actions to reduce variation and waste. It offers the opportunity to challenge the status quo and to look into some breakthrough solutions through the use of idea generation and experimentation[11]. Many tools (statistical and non statistical) can be used in order to achieve such solutions. Tools that are often used include: TRIZ for innovation, design of experiments to identify causes, comparative experiments to validate process changes, comparative F and T tests, Taguchi's loss function and response surface methodology for robust design and optimization[12].

The first suggested solution for students failing the subject was to increase the student's engagement in the subject, in particular, during the time when there is no test week. This was carried out by increasing the number of class tests

and the amount of group work organized for the students. Increasing the number of class tests forces students to study before they come to class and assists them to ask questions when they do not understand the work. Group work, on the other hand, assists students to learn from each other. Studies indicate that students learn better from their peers, while group work forces students to engage in the subject in their own time.

The second solution was to introduce E learning for this subject. All the learning material was placed on line for students to access when they wished to do so. This helped the students to have access to the work done in class, even when they did not attend classes. The introduction of e-assessment, in particular, was effective because it also forced them to test their understanding of the work covered. After the implementation of the above mentioned measures, the following results were reported.

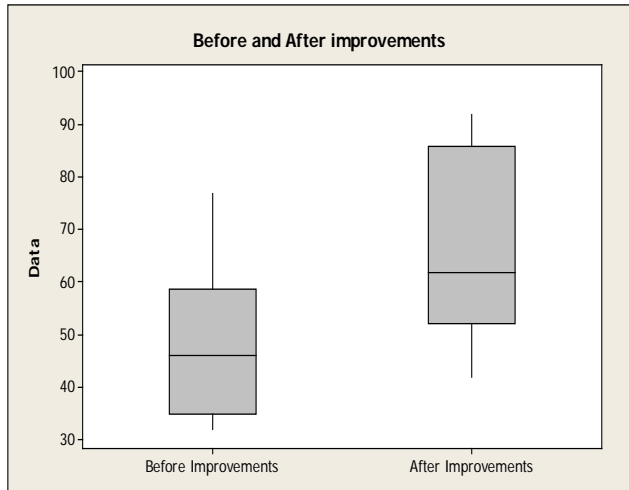


Figure 9: Box Plot for before and after improvements

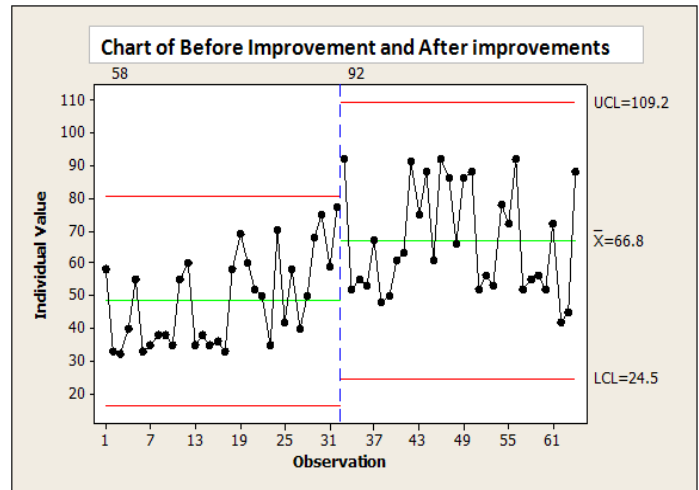


Figure 10: Moving range chart for before and after

The results in figures 9 and 10 indicate that there is an improvement in the test results. The results of the student tests after the initiatives had been implemented improved significantly, as illustrated by the graph. The test average before the improvement was 49%, and after improvement, the average was 67%. This indicates that if students engage with their study material effectively, the students who are prone to fail the subject, might improve their performance; hence strong students will generally do well, whether there are initiatives in place or not.

3.1.5 Control phase – improve the process control and close the project

The control phase ensures that the solution for the problem is sustained in order to control gains and sustain improvements. One must ensure that the correct thinking about the process is inspired. The following elements constitute the activities required to implement the control phase or sustain the breakthrough improvements suggested by [10]: thinking right, managing the process, valuing workers, leading improvements and counting the change. Tools such as control charts, work instructions and visual aids are utilized during this stage in order to continuously monitor the process. Quality audits are employed to validate process improvements and compliance with customers' needs [8].

To ensure that these improvements remain valid, data was collected from the students as to how many students access myTutor regularly. For the first semester of 2010, the subject throughput rate moved from 38 percent to 71 percent. A significant improvement was recorded. QAS 201T had a best student achieving a distinction for this subject for the first time in 10 years.

To ensure that these improvements do not disappear, control measures need to be put in place. Firstly, the updating of myTutor has since formed part of the QAS201T lectures and secondly, continuous audits are being performed to ensure that the standards are maintained. Class tests and group work have been outlined in the study guide, which allows students to interact with their work continuously. The next step is to roll out this solution to the next subject with a low throughput rate, which is Mechanics 1 PHY101T, and to monitor the results.

4. Conclusion

Lean Six Sigma tools can be used to improve processes. In this study, the focus was placed on the engineering education process. The tools identified that Students spent less time on subjects during normal lecture week than they did during the test week; hence the students felt unprepared for the tests. The research also indicated that there is a strong relation between time spent on subjects during a normal week and the test results. The test indicated that if students spend more time during a normal week, they would increase their chances of passing the subject. Control measures are used to maintain the improvements, for example, updating Mytutor, engaging students in group work, and increasing the number of class tests, which would result in better student performance. The improvements were carried out for QAS201T only. In order to improve the industrial engineering throughput, the same initiative must be put in place for all 5 of the subjects that revealed a throughput rate of less than 50 %. The next subject that will be addressed will therefore be Mechanics 1. The team is planning to conduct an awareness session with the lecturer responsible for this subject and to suggest possible solutions.

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