121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #8594

Applying Six Sigma in Higher Education Quality Improvement

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Abstract

Quality in higher education became an important issue due to ever increasing demand by stakeholders and competitive environment. Although six sigma has been successfully used in product and service improvement in the business environment, the concept has not been adapted in higher education. To improve understanding of how six sigma can be used for higher education process improvement toward achievement of quality, a number of models are presented. Six sigma principles such as process improvement, reducing waste and continuous improvement aligns closely with the mission of higher education institutions and accreditation agencies. Using six sigma tools such as statistical process control, lean manufacturing, failure mode and effects analysis can help in the development of sustainable higher quality educational process. A process map with SIPOC (supplier, input, process, output and control), cause and effect analysis, FMEA (failure mode and effects analysis) for higher education was developed and presented. These tools can be used by higher education institutions to better understand the higher education process and how it can be improved to meet the desired quality goals.

Introduction

The concept of Six Sigma was introduced by Motorola in the 1980s to improve their products and maintain quality. The core of Six Sigma lies in the continuous improvement process using the DMAIC (Define, Measure, Analyze, Improve, and Control) method [9]. It has since then been adopted by many other companies to achieve their respective goals both in production of goods and in rendering services. Due to the success of this method, academic institutions attempted to adapt six sigma methodologies to improve the quality of education and services. These concepts have great potential for improving process efficiency and quality of higher education. The improvements can be enhanced by integrating other similar concepts such as lean manufacturing and SPS (statistical process control).

Lean manufacturing was originated as “a philosophy of continuously simplifying processes and eliminating waste”[16]. By streamlining the processes, cycle times for data collection and analysis can be reduced in academic environment due to time constraints faced by students and faculty. The statistical process control (SPC) method uses control charts to analyze variations in a process with predetermined upper and lower control limits (UCL, LCL). Two types of variations are common in any process and are described as follows: (1) random variations, which are the only variations present if the process is in statistical control, and (2) assignable variations, which indicate a departure or deviation from statistical control. The purpose of a control chart is to identify when the process is out of control, thus signaling the need for remedial action. A control chart is a graphical technique in which statistical results are computed from measured values of a certain process characteristic are plotted over time to determine if the process remains in statistical control. Statistical process control charts and run charts are helpful tools for large amounts of outputs such as in manufacturing processes or when dealing with a large student body in a university [12].

Literature Review:

According to Freeman, there is an increasing need to improve the quality of higher education because education is becoming a global entity facing challenges with resource constraints [3]. Unlike other organizations, higher education has several stakeholders such as students, parents, future employers and society [7]. Zhang proposed eight important questions to ask regarding a Six Sigma research program. Of these eight, the most relevant to higher education are: "How can the effectiveness of a Six Sigma program be validated?" "How should Six Sigma be customized for different organizational contexts?", "What is the most effective organizational structure for a Six Sigma program?", and "How do leadership development and human resource practices relate to Six Sigma program?"[19]. The answers to these questions center on empirical validation of effectiveness and customization of the program, separating the Six Sigma program from Quality Control

Adaptation of six sigma approaches in higher education requires careful consideration of differences in stakeholders' requirements and expectations. Unlike business environment, higher education may be perceived by some as non-profit to serve the greater intellectual and societal needs. Decisions in higher education are not always data driven and the need for data is underestimated. An example of a process improvement involves recording scores on the accounting section of the Educational Testing Service standardized test. Additional data such as faculty assignments, textbooks, course design, teaching methods, and course order were collected. To improve average test scores from 42.4% to 46.5%, the input variables were altered. These changes to the program design resulted in an actual increase to 47.3%, above the desired goal[6].

In the study by Razaki & Aydin, different process improvement methods from the business world are analyzed for their usefulness in the academic world. Four different methods were analyzed, including Total Quality Management (TQM), Six Sigma, Business Process Reengineering (BPR), and Lean Manufacturing. "TQM was highly suited to improving the departmental processes to effect a transition to excellence, Lean Six Sigma provided a few but highly effective methods for departmental improvement." The use of Lean Six Sigma was revealed from their analysis of the Kukreja study. It was noticed that the data collection cycle was too long and a great deal of time was necessary to complete the project. Since most students are only enrolled for four years, this did not work well with this required timespan. They propose mixing the appropriate parts of Six Sigma and Lean Manufacturing to make the process more appropriate for the relatively short time available to collect data on individuals. This method uses statistical tools of moderate complexity, with a short cycle time and a focus on elimination of waste [12].

Higher education process can be viewed to be similar to a manufacturing process. In a manufacturing process, raw materials are processed through a series of steps to produce finished products. Similarly, the higher education institutions produce intellectual graduates from incoming students through a series of steps. In higher education, quality depends on several factors such as curriculum, course content, incoming students, teachers, pedagogy, and assessment methods. Since one of the focuses of Lean Manufacturing is reducing waste, it is important to define waste in the higher education system of processes. Examples of educational waste include, "teaching topics already taught in other courses, excessive review of prerequisite materials, unnecessary and redundant introductions, spoon-feeding, teaching obsolete topics, and waiting for unprepared students to catch up" [16]. In order to produce a high quality graduate, efforts to minimize wastes must be undertaken throughout the process with careful consideration of stakeholders' views.

Statistical process control can be a useful tool in the academic environment as the institutional analysis involves a large amount of data such as enrollment trends, graduation rate, retention rates, etc. As every process has an expected degree of variation, it is necessary to determine what constitutes 'normal' variation so that it can be predicted. The more the variation of a process can be minimized or controlled, the more accurately the process results can be predicted." When the process is under appropriate control, the produced variations will be consistent and within the accepted range. The method of SPC can be challenging to apply outside a manufacturing environment, such as a service industry like higher education. In situations where performance parameters are not taken from tangible, measurable products more work is needed. In a study by Roes & Dorr of SPC implementation in the service industry, the key characteristics for process control were defined as the degree to which the service to the customer is indeed intangible, the intensity of involvement of employees in the interaction, and the extent of customer influence on the service provided [13]. For academic environment, the customer would be a future employer, employees would be university faculty, and the service would be the provided education. The SPC approach can be used to improve course instruction, using the following steps:

1. Identify the process to control
2. Determine quality characteristic to monitor
3. Choose the appropriate control chart based on
    a. Type of data
    b. Sample size
    c. Frequency
4. Perform process improvement using SPC tools
5. Implement continuous quality improvement on process [10].

Quality, with respect to higher education has several challenges such as endurance, conformance to requirements, continuous improvement and value added [2]. The process variability not only exists within the students, but within professors as well. For example, grading by professors may be different and the instructional methods may also have variations. In a study by Knight, professors graded unnamed assignments and then re-graded these assignments weeks later to observe the difference in grades received. These grades were then subjected to statistical analysis, finding the average range for each professor. These were then averaged with each other and used to find an upper control limit for the ranges themselves. In future grading, if grades exceeded this range, the assignments would then be re-evaluated [5]

The application of Six Sigma DMAIC methodology to improve quality in engineering educational had been successful in improving the quality consciousness with students and the management of institution [11]. The Six Sigma method can also be applied within the course to continuously improve its quality. The Statistics department of Florida State University, engaged students in seven different projects throughout a course. The first project involved the students listing two contributions they would like to make to their careers. The next five projects followed the DMAIC process, and the final project requires a report on the overall process. In each project, the students applied the DMAIC principles toward achieving their goal, learning the language and function of Six Sigma as they progress [18]. By applying DMAIC, students were able to achieve their goals and familiarize themselves with the system.

The problems associated with change management is challenging in higher education due to the nature of the environment that promotes academic freedom. Academicians have been accustomed with this environment and have individual views towards different issues as well as departmental politics and inter-departmental acrimony that increase complexities associated with any change in the process. "It is estimated that 70% of organizational change initiatives fail completely. Of the ones deemed successful as many as 75% of these fail to achieve their intended result." Individuals do not always get along in an organization, and, when the success of a program is dependent on collaboration, noncooperation can be a hindrance to achieving an organizational change. Given all these problems, there is a question as to whether there truly is a "best practice" for such change. "It appears that many popular management practices labeled as best practices (such as Total Quality Management, Six Sigma, and Lean) are based on anecdotal evidence rather than empirical data." This perception may be due in part to the fact that "the terms 'organizational change,' 'change management,' and 'best practice' appear to be used in a variety of perspectives and research applications but the search for affinity patterns have not resulted in any stable conclusions"[4]. As with many aspects of management, it would appear that flexibilities must be exercised to implement changes appropriate to the environment. Apart from the students, teachers and the management involved, the infrastructure and educational resources that students access also proves to be vital in achieving a higher quality education [14].

Six Sigma Methodology:

Statistically Six Sigma quality defines limiting the number of defects to 3.4 (parts per million PPM). The term Six Sigma refers to the six standard deviations away from the mean in a normal distribution or bell shaped curve. It uses the measurement of factors in a process and works on improving the output based on continuously improving the system and its processes. The defects in a Six Sigma process are the total area to the right and left of $+6\sigma$ and -6σ respectively as shown in Figure 1.

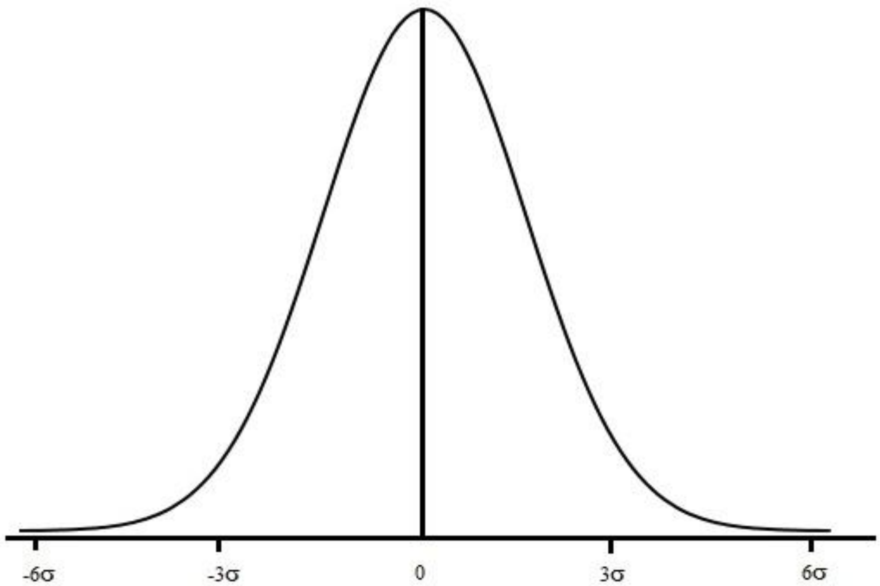

Figure 1: A normal distribution curve with six sigma (σ = 0 at mean)

Among different approaches used towards achieving six sigma level of quality, the DMAIC and the focus is on continuous improvement lies in the heart of six sigma process. DMAIC is an abbreviation for Define, Measure, Analyze, Improve and Control. The following section of the paper attempts to demonstrate how DMAIC methodology can be used to continuously improve the quality in higher education.

Define Phase:

In the design phase, the goals and the parameters must be clearly identified and defined. Six Sigma methodology can be effectively used in higher education institutions [1]. The first step to understanding the process is to develop a process map for higher education and then construct a cause-effect diagram to evaluate the effect of input variables on output. A process map for higher education is presented in figure 2 and compared to a manufacturing process as shown in figure 3. The potential suppliers of higher education are educational institutions such as high schools, community colleges or universities. The input consists of new first year students, transfer students, K-12 teachers, and high school graduates. The Process involves a sequence of steps from which a student takes various course over a period of time and graduates. The customers consist of employers, graduate schools, society, and others, as some students may be self-employed.

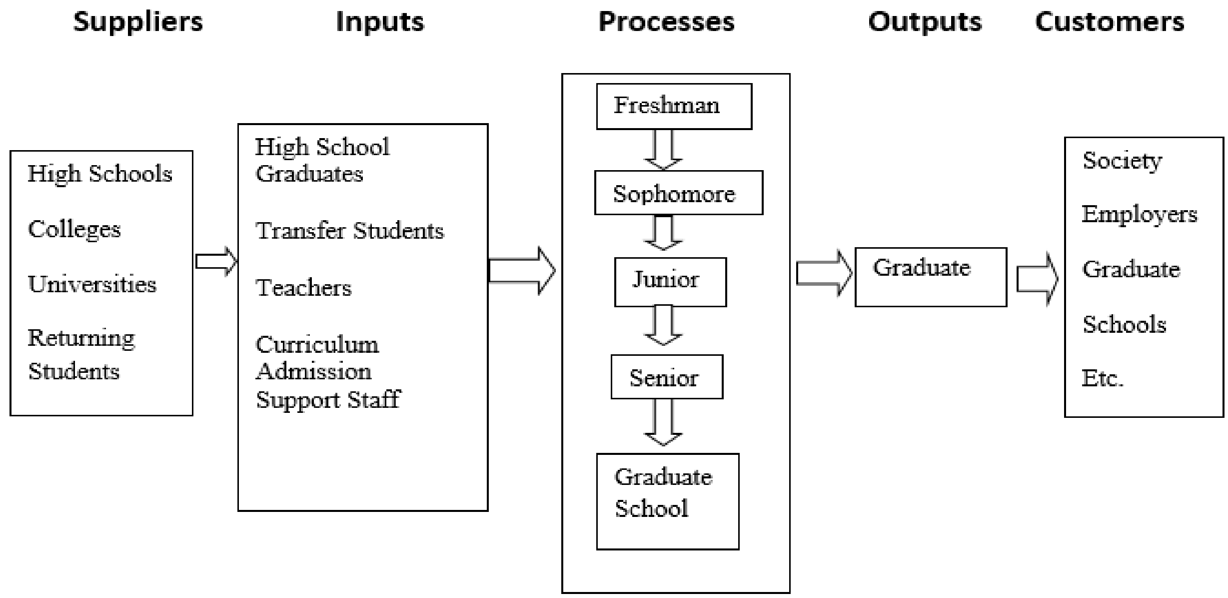

Figure 2: Six Sigma Process (SIPOC) in Higher Education

Figure 3: Process flow in a conventional manufacturing process

Measure Phase:

In the measure phase, all measurements related to the process are calculated. Although a number of different measurement tools can be used in this phase, an example of SPC is presented in this paper. Among different factors affecting quality of education process and student performance, the important ones may be GPA, professors' performance, number of students in each class, course materials and course order. The factors used to measure student success are student retention rate, graduation rate, and percent employed in the field related to academic degree immediately after graduation as presented in Figure 4. These variables can be analyzed using SPC to identify which input or inputs have the greatest effect on the outputs. Some of the inputs do have dependencies on each other and this will be analyzed as well to ensure the accuracy of the analysis.

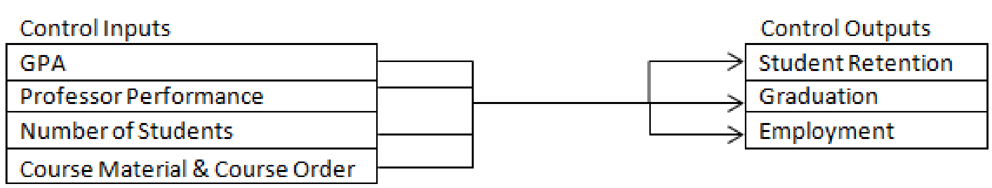

Figure 4: Output Controls and its dependency on Inputs

Both quantitative and qualitative control charts have been developed to monitor the performance of individual student and the institution. The two quantitative charts are the Individual/Moving Range chart (IX/mR) and the Average/Range chart ($\overline{X}$/R). To monitor an individual's performance IX/mR chart was developed using the following steps.

1. Gather the data. (Verify data validity by considering the collection method.)
2. Calculate the moving ranges (difference between each successive data point).
3. Plot the data in time ordered series (Individuals [IX] chart)
4. Plot the moving ranges in time ordered series on the moving range (mR) chart.
5. Calculate the following formulas provided on the following pages:
    a. Average of all the moving ranges ($\overline{mR}$)
    b. Estimate of the sigma/standard deviation ($\overline{mR}/d_2$)
    c. Average of all the data points ($\overline{X}$)
6. Plot the lines representing the averages, LCL's, and UCL's on the IX and mR charts.

Table 1: Courses and GPA in the class with moving range (mR)

Class Level	Course	GPA Received	mR
Freshman	EGR102	4	
Freshman	EGR280	3.3	0.7
Freshman	EGR230	3.7	0.4
Freshman	EGR260	3.3	0.4
Freshman	EGR165	4	0.7
Sophomore	EGR310	3	1
Sophomore	EGR350	3	0
Sophomore	EGR353	2	1
Sophomore	EGR330	3.3	1.4
Sophomore	EGR356	3.7	0.4
Junior	EGR370	2.7	1
Junior	EGR315	2.7	0
Junior	EGR321	2	0.7
Junior	EGR392	1.3	0.7
Junior	EGR380	2.7	1.4
Senior	EGR399	3.3	0.6
Senior	EGR432	3.7	0.4
Senior	EGR410	3	0.7
Senior	EGR465	3.7	0.7

The current study for an individual student was based on the grade point average (GPA) in the courses related to their major. The students' academic progress was considered as a single process for application of SPC recognizing variations in courses, professors, and levels. For example, a student in the Mechanical Engineering program requires five prerequisite courses, eight core courses, and seven elective courses with a total of 20 engineering courses. Table 1 shows the moving range chart for GPA in the engineering courses. The upper control limit

(UCL) and lower control limit (LCL) of moving range and individual control chart is presented in Table 2.

Table 2: UCL and LCL of Moving range and Individual Control Chart

Moving Range (mR) Chart Data	
Average mR	0.673684
Estimate of Sigma	0.597232
UCL (mR)	2.200963
LCL (mR)	0

Individuals (IX) Chart data	
Average GPA	3.07
UCL (IX)	4.861713
LCL (IX)	1.278287

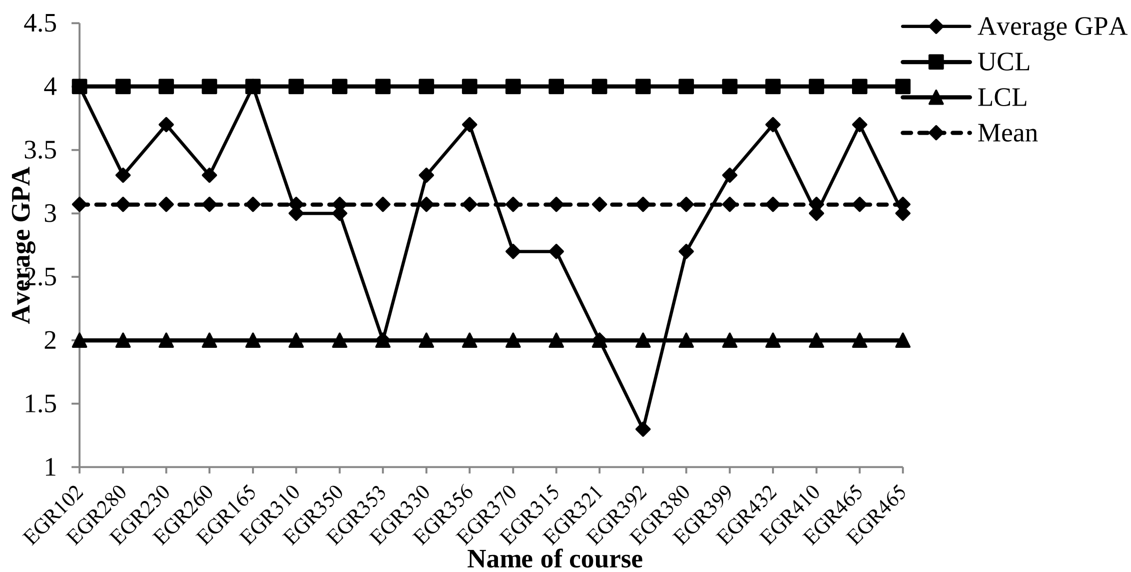

Figure 5: Average GPA of students in each course

A control chart for students' GPA in different engineering courses is presented in Figure 5. The UCL of 4.0 represents the maximum attainable GPA and the LCL of 2.0 represents the minimum required GPA required by the university to be in good standing. Students with less than a 2.0 GPA are placed on academic probation and may be terminated if they fail to improve their GPA. It can be observed from the control chart that the process is not in control for two courses. The average GPA for EGR 353 (Thermodynamics) is at the lower limit of control chart and the average GPA for EGR 392 is lower than the lower control limit. This clearly identifies improvement needs in these two courses, as the success rate of students in terms of GPA is less than expected. Figure 6 shows the moving range showing any significant difference between two successive control points. All the points in the moving range chart are within the control limits and hence there is no control point with significant difference compared to its successive control point.

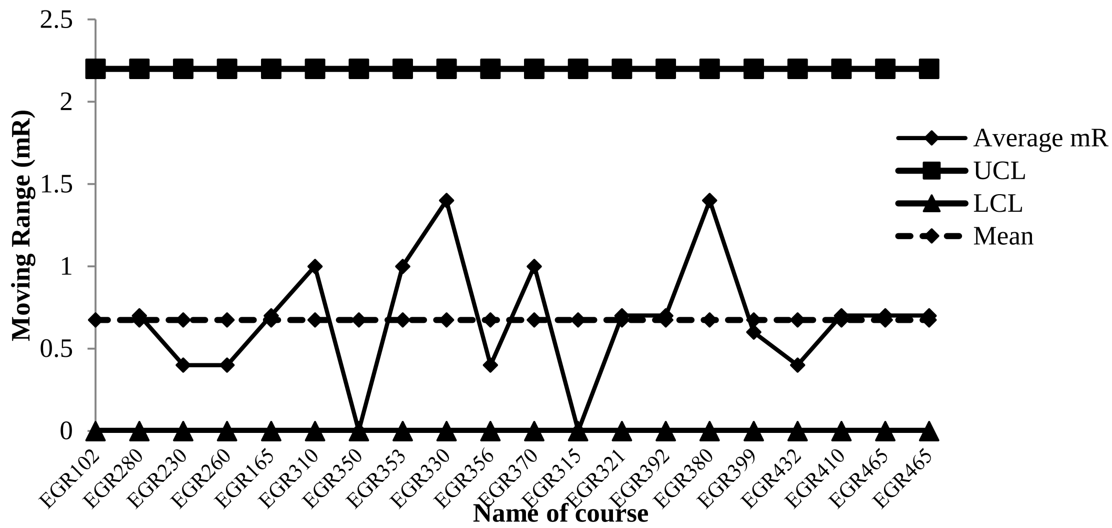

Figure 6: Moving Range (mR) across each course

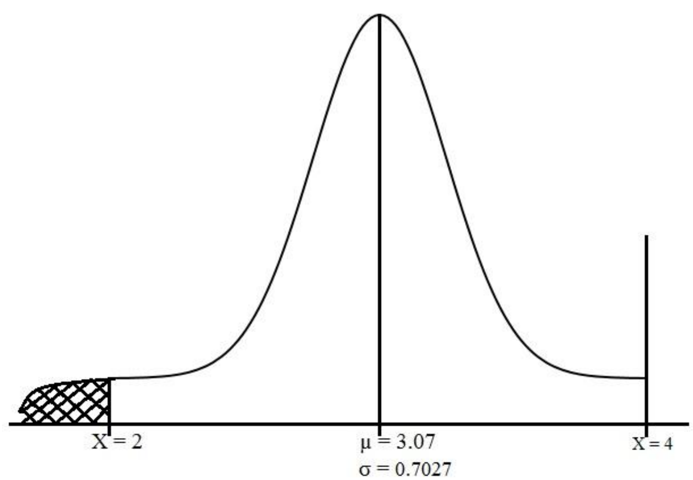

Figure 7: Normal Distribution (Bell Curve) of student's grade (GPA)

Figure 7 shows the normal distribution curve for the student's grade. The right side of the curve has a maximum value of 4 with the minimum value as zero. The average value of GPA (μ) from the current set of data was 3.07 with a standard deviation (σ) of 0.7027. The students with less than a 2.0 GPA may be considered as the defects in the system as shown in the area of normal distribution curve to the left of X = 2. The area to the left of X = 2 was calculated as 0.06392 which means that approximately 6.4% of the students received GPA of less than 2. Therefore, the defects per million is 63,920 that meets 3σ level of quality in the process. To achieve six sigma level of quality the value must be reduced significantly.

Analysis Phase:

After the development of the process map, it is important to identify the causes for poor quality in higher education. A cause and effect or fishbone diagram is a widely used approach to identifying the root causes and their effects. The sources of poor quality were identified as curriculum, teachers, students, assessment, and the academic and social environment. The possible causes from each of these sources have been schematically shown in figure 8. The fishbone diagram displays the root causes from six different sources that contribute to poor quality of education. Identification of these sources can help in making changes to improve quality of education.

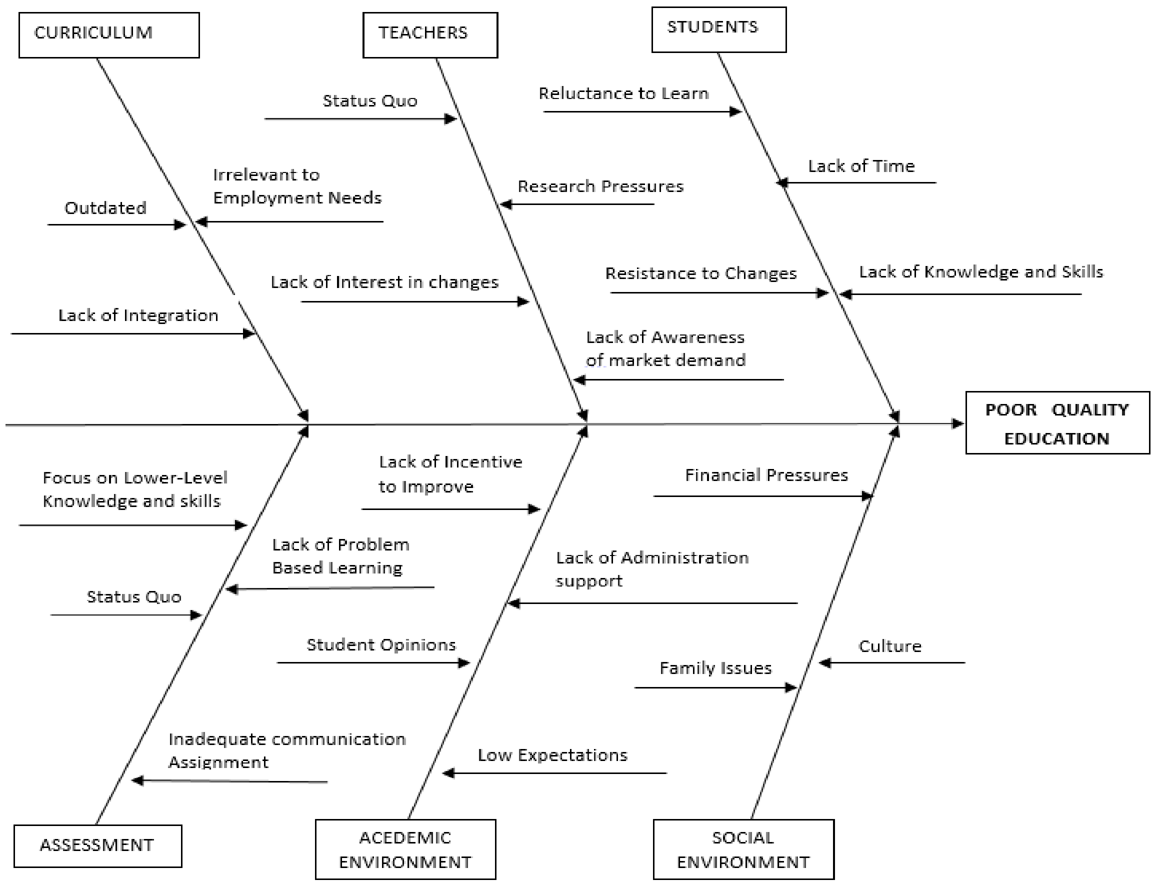

Figure 8: Cause and Effect Diagram of Quality of Higher Education

Improvement Phase:

In the improvement phase, the causes for failure or poor quality must be identified with a solution that will reduce defects in the process. A failure mode and effect analysis or FMEA can be used to improve the process. These quality tools could be very well used for the improvement of organizations and institutions [17]. A step-by-step procedure is used to identify all possible causes of failure and their corresponding effects with recommended corrective actions to avoid the failure modes. Quality needs to be properly assessed with respect to students, teachers, departments and Institutions, which makes curriculum [15]. A FMEA was developed to address the above factors as shown in Table 3.

Table 3: A Failure Mode and Effect Analysis of Higher Education Process

Process step	Failure Mode	Failure effect	Failure cause	Controls/Preventive action	Recommended action	Responsibility
Students	Reluctant to learn	Students having a GPA less than 2/Students skills and knowledge not matching the industry requirements	Lack of interest	Internal Assessment	Educate on the importance of education	Teachers
	Lack of time		Bad time management	Personal Assessment	Educate and provide techniques on time management	
	Resistance to changes		Lack of interest/Unaware of advantages of new changes	Feedback from teachers	Educate on the importance and benefits of change	
	Lack of knowledge/ skills		Knowledge and skills not transferred properly	Feedback from teachers	Make sure knowledge is transferred properly from teachers to students	
Teachers	Research Pressures	Students having a GPA less than 2/Students skills and knowledge not matching the industry requirements	Concentrating on lot of research work	Number of research articles to be presented	Limit the number of research work depending on the work load each semester	Teaching fraternity, Management and authorities of the Institution and Curriculum
	Lack of interest in changes		Lack of interest/Unaware of advantages of new changes	Internal Assessment	Educate on the importance and benefits of change	
	Lack of awareness of market demand		Less interaction with industry/No source of update	Educational content up to date	Constantly be in contact with people in industry and latest technology	
	Status Quo		Unwilling to change	Open to change	Educate on the importance and benefits of change	
Curriculum	Outdated	Students having a GPA less than 2/Students skills and knowledge not matching the industry requirements		Educational content up to date	Constantly be in contact with people in industry and latest technology	Teaching fraternity, Management and authorities of the Institution and Curriculum
	Lack of Integration			Management Assessment		
	Irrelevant to employment needs		Less interaction with industry/No source of update	Updated curriculum		

Control Phase:

The control phase requires institutionalization of the improvement results obtained from the Six Sigma process for sustainability. The key to success in achieving quality is to standardize the improvement process and fostering a six sigma or continuous improvement process in the organizational culture. The results of the new standardizations or procedures can be further improved using different six sigma tools and procedures with a goal of reducing variation or defect in the process. Control charts are an effective way of statistically keeping a track of performance and using the data for continuous improvement in Six Sigma methodology [8].

Summary

A number of six sigma models have been developed and presented to improve quality in higher education. The key inputs and output variables were identified in the define phase of DMAIC process. The input and output variables were measured by collecting the data over time. The analysis phase used SPC to identify the variables outside the control limits. After identification of the variable that lies outside the control limits, appropriate corrective actions can be implemented for process improvement. This phase is considered important in academic environment, as it is critical to student success and quality improvement. In the control phase, the input and output variables require continuous monitoring to ensure sustainable process.

Conclusion

The higher education process showed a three sigma (3σ) level quality that requires significant improvement to achieve six sigma (6σ) level. The primary objective of higher education is student success through higher quality education where failure of any student may be considered as a defect in the process. Due to variability in the process such as different type of instruction by different professors, a variation of quality exists. Variations of quality may be due to lack of understanding of how students learn and adapting to different learning styles of students. After identification of the issues and defining the problems, a solution can be developed using six sigma approaches and models presented in this paper. A control chart can be used with UCL and LCL along with a continuous improvement plan to improve the higher education process. This will result in higher quality and sustainable process in the institution with higher levels of student satisfaction and success rates such as graduation and retention rates. The information and tools provided in this paper is an attempt to shed some lights on how different quality improvement models can be used in higher education.

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