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Original Article

Integration of Six Sigma and European Fundamental Quality Management for Continuous Improvement of the Mechanical Engineering Course in Higher Education

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Abstract - *The objective of this research paper is to assess and demonstrate the integration of the Six Sigma-Define-Measure-Analyze-Improve-Control (DMAIC) methodology and the European Fundamental Quality Management (EFQM) technique for continuous course quality improvement in one of the courses at a Higher Educational Institution (HEI). The researchers used participatory action research methodology to improve the teaching-learning process and course delivery to students in a Mechanical Engineering course at a higher education institution. Six Sigma could enhance course quality by lowering failure rates and focusing on continuous improvement; European Fundamental Quality Management could provide timely feedback. There have been few studies that integrate Six Sigma and the European Fundamental Quality Management model for Continuous Improvement of the teaching-learning process.*

Keywords - *Continuous quality improvement, DMAIC, EFQM, Higher education, Six Sigma.*

1. Introduction

The overall development of a nation depends on the quality of human resources in the country. Higher education sectors like engineering colleges have a significant role in improving the quality of human resources. Hence, the quality of engineering graduates is very important in higher education. The higher education system in India is composed of public, private, and mixed. Presently, the technical educational sectors face severe competition impacted by the fastest growth rate in educational institutions. Because of global economic, social, technological, and political changes, Higher Education Institutions (HEIs) are under tremendous strain these days [1].

Competition in HEIs is compelling the institutions to try hard for students and funds to ensure their sustainability [2]. These service sectors face significant problems like unemployability of graduates, poor academic performance, and results [3]. However, Universities are showing interest in Six Sigma and working systematically to improve business processes and the services delivered to students, industry partners, faculty, and researchers [4].

Six Sigma, which Motorola developed in the early 1980s, is an efficient and precise application of tried-and-true quality tools and techniques [5]. Like industries, customer dissatisfaction can be considered a defect in the service sector [6]. Six Sigma is a strategy for locating and eliminating the causes of such defects or failures in processes by focusing on critical final outputs to end users. Adapting Six Sigma approaches from the industrial sector to academic activities can improve quality in the educational services sector.

This research aims to apply Six Sigma approaches to mechanical engineering courses at a higher education institute in order to reduce failure rates and improve course quality. Numerous studies [1, 2, 4] have been published on using lean approaches in conjunction with Six Sigma in higher education institutions. Some papers also report integrating various quality management systems with Six Sigma [7].

Six Sigma for continuous improvement of a specific course is rarely studied. The integration of the European Fundamental Quality Management (EFQM) technique for constant improvement is a novel approach to academic quality improvement in a specific division of higher education. It collects timely feedback to correct defects or failures in the teaching-learning process in HEI.

1.1. Six Sigma in HEIs

To address quality challenges, educational institutions use a variety of strategies that have proven successful in industries [8]. Six Sigma is the most effective strategy in the educational services sector for improving students' academic

performance and employability [1]. To sustain high academic quality, higher education institutions should consider Six Sigma as a practical approach [7]. Also, for solving learning problems that students encounter during their studies, HEIs can incorporate the Six Sigma-Define-Measure-Analyze-Improve-Control (DMAIC) methodology in the teaching-learning process. The Six Sigma DMAIC tool can directly improve student performance in a subject [9].

Six Sigma methodologies can be used to develop curriculum, course plans, and teaching methods in order to foster a quality culture in institutions [10]. To create a Six Sigma culture in institutions, employees must be trained in Six Sigma tools [3], and students must also participate in Six Sigma and other initiatives [11]. However, institutions struggle to attract high-quality students due to the increased number of engineering colleges [12]. Based on global experiences, a creative tool such as Six Sigma is the best option for any HEI seeking to enhance service quality [11].

Managerial commitment, proper Six Sigma training, and employee resistance are essential factors affecting Six Sigma implementation in higher education institutions [13]. To ensure quality, HEIs must also address industrial quality indices in their service products, such as fitness for purpose, perfection, and value for money [14].

1.2. EFQM and Continuous Improvement

Continuous improvement systems aim to provide the best education possible to every student in the higher education system [15]. The EFQM model is a framework for the European Quality Award, and the model is a method of achieving excellence in the performance of an organization. The model can be applied to every section within an organization, irrespective of field, magnitude, or age [16].

This paper uses one of the EFQM guidelines to assess customer satisfaction. Several organizations worldwide have successfully implemented Six Sigma DMAIC to ensure customer focus and continuous improvement of operations [17]. The authors used the Six Sigma-Define-Measure-Analyze-Improve-Control (DMAIC) methodology and the European Fundamental Quality Management (EFQM) technique in this paper to continuously improve the teaching-learning process in a specific branch of a technical education system. Also, they analyzed the problems encountered during the application.

Stakeholders play vital roles in all Six Sigma initiatives [18]. Students, teachers, parents, and the government are among the most critical stakeholders in the University. They may also be considered university customers. In higher education quality management, student feedback is vital [16]. Six Sigma should be integrated with university strategies and top management commitment to continuous improvement in higher education institutions [19].

Customer satisfaction is essential in implementing Six Sigma in any service sector [5]. To achieve customer satisfaction, identifying customers and their expectations is a fundamental requirement [20]. Improving the efficiency of service delivery and reducing waste can impact student satisfaction [21]. The continuous assessment technique can also serve as a means of communication between students and lecturers [22].

2. Method

The researchers carried out extensive research based on the indexed databases with subtitles, abstract, and keyword searches for Six Sigma, higher education, Lean, DMAIC, various quality management systems like Total Quality Management, ISO 9000, accreditation systems in India, Six Sigma DMAIC methodology, EFQM, statistical quality management, and control tools.

The researchers studied papers from 2010 to 2019. The articles and textbooks available in this area were also extensively searched and reviewed. The authors reviewed the history and development of technical education in India and the employability of graduates from the present technical education system. The study was conducted at one of the institutions under a technological University in southern India. Established in 2015, the University is emerging as a leading player in India's technical education sector. The authors used the DMAIC methodology to reduce the defect rate, and the EFQM survey was applied to improve the satisfaction of significant stakeholders.

This study guides instructors in reducing the defect rate in students' academic performances. The objective is to enhance the quality of teaching by continuous improvement in instructional activities. In an ongoing improvement strategy, it is necessary to collect course reflection and feedback from primary customers of HEIs. The paper tries to demonstrate the research question as shown below.

RQ: How can HEIs integrate the Six Sigma DMAIC methodology and EFQM model for continuous improvement of courses?

2.1. Continuous Course Improvement in Higher Education

The researchers applied a participatory action research approach to demonstrate the method of applying LSS for continuous course improvement in HEIs. The object of this research was to continuously improve the quality of teaching by reducing failures in the delivery of courses.

The subject of study is a Teaching-Learning Process (TLP) under a reputed University in India. The action research setting includes a specific subject from a mechanical course at an engineering college. The authors applied the Continuous Improvement (CI) philosophy to this course during the six-month term of study.

Table 1. Evaluation and feedback points

Course Module	Evaluation and Feedback Point
1	
2	
First Internal Examination	Feedback 1st Mid-Term
3	
4	
Second Internal Examination	Feedback 2nd Mid-Term
5	
6	
Feedback Final	
Final Examination	
Course Completion	

This study proposed conducting two evaluations at the end of the first and second internal examinations for continuous course improvement. The proposed evaluation and feedback points are depicted in Table 1.

The syllabus of the course selected for improvement contains six modules. In this proposed system, the teaching-learning process of the course was divided into three phases. The first feedback of the course was taken after the completion of the first two modules out of six and the corresponding internal examination.

The second feedback was collected after completing modules 3 and 4 and the related internal examination. In addition, final feedback was collected at the end of the course period. In this system, the second half of the course was redesigned based on the feedback from the first evaluation.

Additional inputs for the final examination must be given to students based on feedback from the second internal examination to ensure continuous improvement. Figure 1 depicts a high-level process map for the existing teaching and learning system in Indian technical institutions. The proposed high-level process map for the teaching-learning process in technical institutions is depicted in Figure 2.

3. Six Sigma DMAIC Implementation

The authors applied Six Sigma DMAIC to one of the courses in the pre-final year of study. The project selected was the continuous improvement of student's academic performance in the course with code 'ME 303 Machine Tools and Digital Manufacturing (MTDM)'.

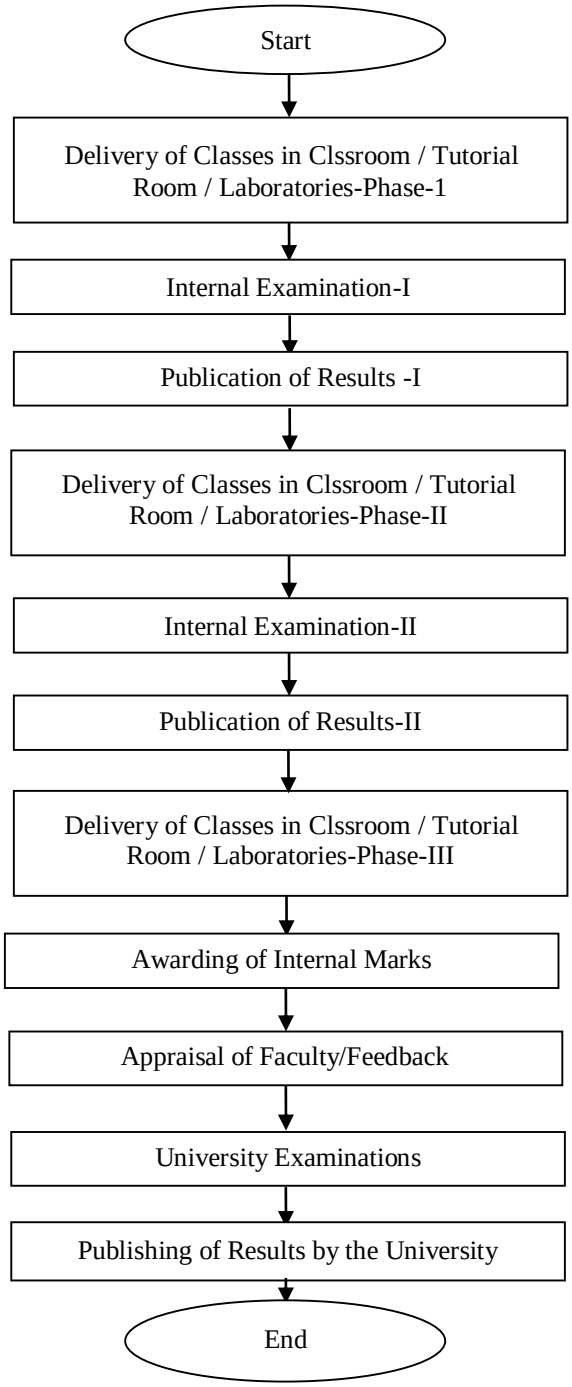

Fig. 1 High-level process map-TLP-existing system [10]

The chosen course was a little challenging to learn, frequently resulting in students' failures in the end-semester examination. As a result, improving the teaching and learning process was critical for this course.

In this research, the implementation of Six Sigma DMAIC was concentrated primarily on the first phase of the teaching-learning process. The authors applied the statistical tools, project charter, and SIPOC diagram in the define phase.

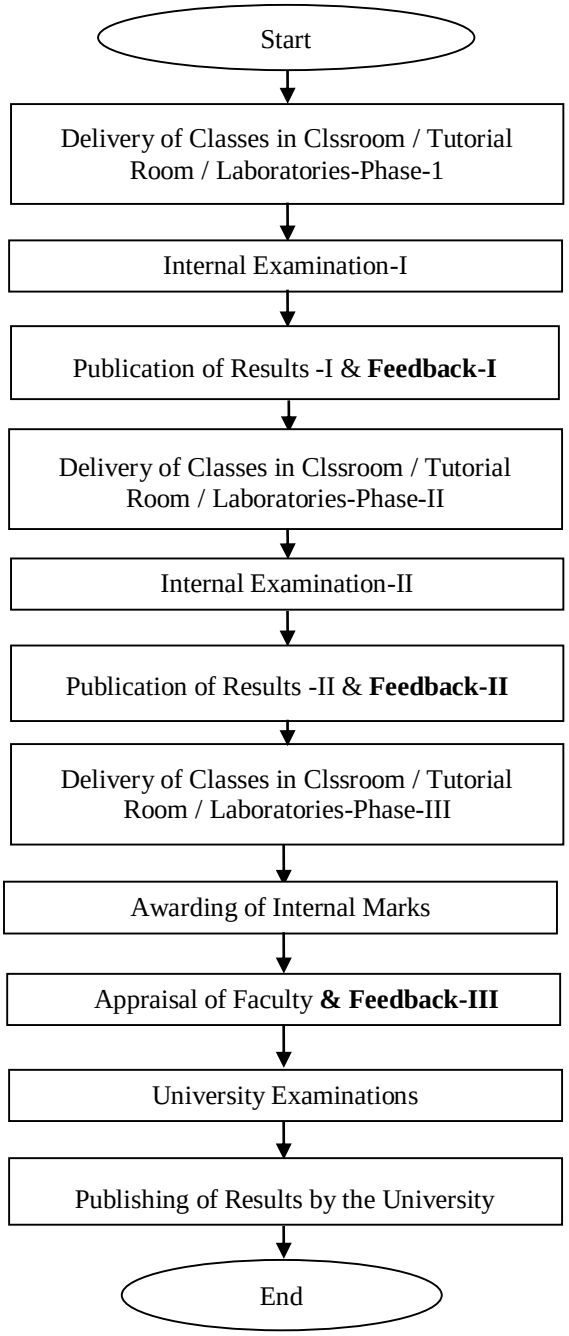

Fig. 2 High-level process map-TLP-proposed

The defect rate after the first internal examination was measured in the measure phase. The Defects Per Million Opportunities (DPMO)-Six Sigma table [18] was applied to calculate the process's capability. Bar charts and cause-effect diagrams were applied in the analysis phase to identify the root causes of the problems. Through brainstorming sessions among the project team, improvement plans were developed in the improvement phase.

The statistical tool, Failure Mode and Effects Analysis (FMEA) was applied to identify the root cause of problems. The 'control plan' was used in the control phase to maintain the sustainability of improvements. Understanding the customer needs associated with each process is critical for determining the Critical-to-Satisfaction (CTS) characteristics [23].

To identify CTS characteristics as part of implementing Six Sigma DMAIC, a survey feedback form based on the European Fundamental Quality Management (EFQM) model was designed. The EFQM feedback form is a quality model designed to improve quality in European universities. The EFQM-based form was distributed to students to assess stakeholder satisfaction in teaching-learning.

The learning process was measured and analyzed under three categories, 'resources,' 'course content,' and 'course delivery'. The teaching process was measured and analyzed in two categories: 'Faculty' and 'Evaluation and Feedback System.' Each section contained some statements to deepen the quality concern. Each statement had two different dimensions, such as agreement and importance.

Under the EFQM assessment, the students are directed to rank their agreement with the statement. They are also directed to state the level of importance of that statement from their perspective [16]. A four-point Likert scale was applied to both dimensions for making specific responses. The 'important' dimension measures students' responses regarding how important the statement is in their point of view. The 'agreement' statement depicts the extent to which the statement is true at the particular institution. The gap between importance and agreement indicated the degree of satisfaction level of stakeholders.

3.1. The Define Phase

The define phase was applied to explore the existing system of the teaching-learning process. The statistical tools, the SIPOC diagram, and the Project Charter were used to define the problem. The SIPOC table presents elements of the process improvement project, such as the suppliers, process inputs, and customers [23]. The SIPOC diagram also depicts an overview of the complete functions of the process taken for improvement [5].

The faculty handling the course was considered the supplier of the SIPOC analysis table. The Teaching-Learning Process (TLP) in the subject MTDM involves completing a syllabus containing six modules. The process outputs were identified as attendance percentage and marks on internal examinations and assignments. The course's students were considered the customers of the teaching-learning process. Figure 3 shows the SIPOC diagram.

Table 2 shows the statistics tool project charter. The project charter outlines the scope and objective of Six Sigma implementation.

Suppliers	Inputs (X)	Process	Outputs (Y)	Customers
Faculty Handling the Course, MTDM	Attendance Register in the Course Diary Teaching and Course Notes Internal Examinations Assignment Questions	Attending the Classes	Attendance Percentage	Students Attending the Course, TDM
		TLP on Module 1	Marks on Internal Test 1: CO1	
		TLP on Module 2	Marks on Internal Test 1: CO2	
		TLP on Module 3	Marks on Internal Test 2: CO3	
		TLP on Module 4	Marks on Internal Test 2: CO4	
		TLP on Module 5	Marks on Internal Test 1: CO5	
		TLP on Module 6	Marks on Internal Test 2: CO6	

Fig. 3 SIPOC diagram

The selected project aims to improve students' academic performance on the topic of MTDM. This course's defect rate has been extremely high for the past two years. As a result, the institute performed poorly. This Six Sigma project aims to improve academic performance by achieving a 100% pass rate.

3.2. Measure Phase

The Measure phase is the second stage of Six Sigma DMAIC. The current state of the teaching-learning process for the topic MTDM was assessed at the evaluation and feedback stage following the first internal examination. The performance of the initial internal examination was evaluated by measuring the process's capabilities. The eight students who failed in the first phase were chosen as defects. These defects are to be corrected to achieve zero defects in the teaching-learning process in the MTDM course. They were chosen and treated for improvement and further analysis using the Six Sigma DMAIC method.

Table 3 displays the process capability calculations from the first phase of internal examinations. In this study, a 'defect' in higher education is defined as a student who fails to satisfy the college's minimum credit level for a pass. During the first internal examinations, eight students fell out of 62. The Defects per Million Opportunities (DPMO) was calculated based on the number of defects. The use of DPMO-Process capability tables calculated the process capability. The processing capability was measured at a sigma level of 2.625 after the first internal examination. The root causes of defects and the degree of satisfaction of students were estimated by conducting a satisfaction survey based on the EFQM model.

3.3. The Analyze Phase

The Analyze phase assesses the potential improvement strategies based on the data collected in previous phases [23]. A project team was constituted, with the staff advisor and faculty members handling the other courses. The team evaluated the data collected from the measure phase to identify the root causes of the eight defects. Figure 4 depicts the cause-and-effect diagram generated by brainstorming sessions among project team members. It shows the factors affecting defects in HEI. Table 4 shows the critical analysis of identified defects. Most of the students were not conforming to the required minimum quality.

For further DMAIC analysis, the eight failed students selected for improvement were numbered from defect 1 to defect 8. The causes of defects were analyzed under four categories: performance in internal examinations, attendance percentage, ability, and attitude of students. The ultimate objective of this phase was to critically analyze the root causes of problems that occurred during their teaching-learning process.

The performance of students was measured and analyzed based on the first internal evaluation, and it was found that none of them conformed to the standard quality requirement of 45% marks. The attendance percentage at the time of evaluation was satisfactory for most students. The project team critically analyzed the ability of these students in language skills, communication skills, leadership quality, and ability to work in groups.

On critical analysis of the student's ability, it was found that defect no.1 and defect no.5 needed improvements in language and communication skills. The leadership quality and the ability of students to work in groups were good except for defect no.5. The defects were analyzed under the attitude attribute. The attitude was tested in terms of the interest of students in academic activities, rate of submission of assignments, and sincerity in attending classes. Defect 1 and defect 6 needed improvement in the sincerity of attending classes. The interest in academic activities and the submission of assignments by defect 5 was not satisfactory.

Table 2. Project character

Project Name/Number	Improvement of academic performance of students in MTDM/SSPS5ME3031			
Sponsoring Organization	Engineering College			
Project Sponsor	Name: Head of Department	Phone:		
	Office Location: Engineering College	Mail Stop:		
Project Black Belt	Name: Self	Phone:		
	Office Location: CEMP	Mail Stop:		
Project Green Belt	Name:	Phone:		
	Office Location:	Mail Stop:		
Team Members (Name)	Title / Role	Phone	Office Location	Mail Stop
	HOD		Engineering College	
	BB	Self	Engineering College	
	MBB	Self	Engineering College	
Principal Stakeholders	Title / Role	Phone	Office Location	Mail Stop
Students of ME Dept.			CAMP	
Date Chartered:	Project Start Date:	Target Completion Date:		
	1st August 2019	30th November 2019		
Revision: N/C:	Number: 0	Date		
	Sponsor Approval Signature:			
Project Name/Number:	Improvement of academic performance of students in the subject MTDM/SSPS5ME3031			
Project Mission Statement	The project aims to achieve a 100% pass percentage in the Mechanical Engineering Department. Zero defect rate with six sigma capability			
Problem Statement	This course's failure/defect rate increased considerably in the last two years, reducing the department's overall results. The poor results in departments, in turn, resulted in poor academic performance of the institute.			
Project Scope	The six sigma project SSS5ME3031 will improve the student's academic performance by ensuring a 100% pass.			
Business Needs Addressed by This Project	Poor results affect the institute's reputation, reducing students' intake.			
Product or Service Created by This Project (Deliverables)	Improvement in academic performance of students in the subject MTDM			
Resources Authorized for This Project	Faculty handling manufacturing subjects cluster			

3.3.1. EFQM Survey

Six Sigma is a customer-focused methodology that will increase internal and external customer satisfaction [24]. Along with academic performance improvement, customer satisfaction is essential for successfully deploying Six Sigma DMAIC in HEIs. Appendix 1 shows the students' satisfaction EFQM feedback form distributed among the students for measuring and analyzing satisfaction levels.

The survey found a small gap in almost all the attributes tested among the students. Table 5 shows the consolidated results of the EFQM student satisfaction survey. Student feedback results identify students' satisfaction levels with various attributes of the teaching-learning process. The results were analyzed by measuring the gap. The gap is the difference between the degree of importance and level of agreement in statements.

Table 3. Process capability-first phase

Product/ Process/ Subject	Defect	Unit	Opportunity	Total Opportunity	DPU	DPO	DPMO	Process Capability (Sugma Level from Tables)
	No. of Failures (2)	No. of Batches (3)	No. of Students / Batch (4)	(5)=(3)x(4)	(6)=(2)/(3)	(7)=(2)/(5)	(7) x 10,00,0000	
SSS5ME303 1MTDM	8	1	62	62	8	0.129032	129032	2.625

Table 4. Critical analysis of defects

Student Roll No.	Defect Number	Ability				Attitude			Performance Test Score (%)	Attendance (%)
		Language / Communication Skill	Leadership Quality	The Ability of Students to Work in Groups	Innovative Skills	Sincerity in Attending Classes	Interest in Academic Activities	Submission of Assignment		
40	Defect 1	Not Satisfactory	Satisfactory	Excellent	Good	Not Satisfactory	Not Satisfactory	Satisfactory	40	66
51	Defect 2	Satisfactory	Good	Excellent	Satisfactory	Satisfactory	Satisfactory	Good	25	76
57	Defect 3	Satisfactory	Satisfactory	Good	Satisfactory	Good	Good	Good	40	80
62	Defect 4	Satisfactory	Good	Good	Satisfactory	Good	Satisfactory	Good	30	80
65	Defect 5	Not Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Not Satisfactory	20	76
66	Defect 6	Satisfactory	Good	Good	Satisfactory	Not Satisfactory	Not Satisfactory	Satisfactory	30	70
67	Defect 7	Satisfactory	Good	Good	Satisfactory	Good	Satisfactory	Satisfactory	35	80
69	Defect 8	Satisfactory	Good	Good	Satisfactory	Good	Satisfactory	Satisfactory	25	66

Table 5. EFQM student satisfaction survey-results

Sl. No.	Teaching Learning Process-Students Satisfaction Survey			
		Agreement (AGR)	Importance (IMP)	GAP=IMP-AGR
1	Learning Process-Resources	2.7	3.233333333	0.533333333
2	Learning Process-Course Content	1.833333333	2.133333333	0.3
3	Learning Process-Delivery of Courses	1.783333333	2.083333333	0.3
4	Teaching Process-Faculty Performance	2.985185185	3.118518519	0.133333333
5	Teacing Process-Evaluation Feedback System	3.013333333	3.346666667	0.333333333
	Overall Satisfaction	2.8	3.466666667	0.666666667

It is possible to prioritize the problems to be corrected by measuring the gap between importance and agreement. On analysis, gaps were found in all the six parameters tested among the students. Appendix 2 shows the detailed results of the EFQM student satisfaction survey. Figure 5 shows the results of feedback on the learning process concerning resources. Gaps between importance and agreement were more in the availability of resources like e-journals and IT resources (Survey question no.Q1.4), National journals and International journals (Q1.5), and equipment (Q1.6).

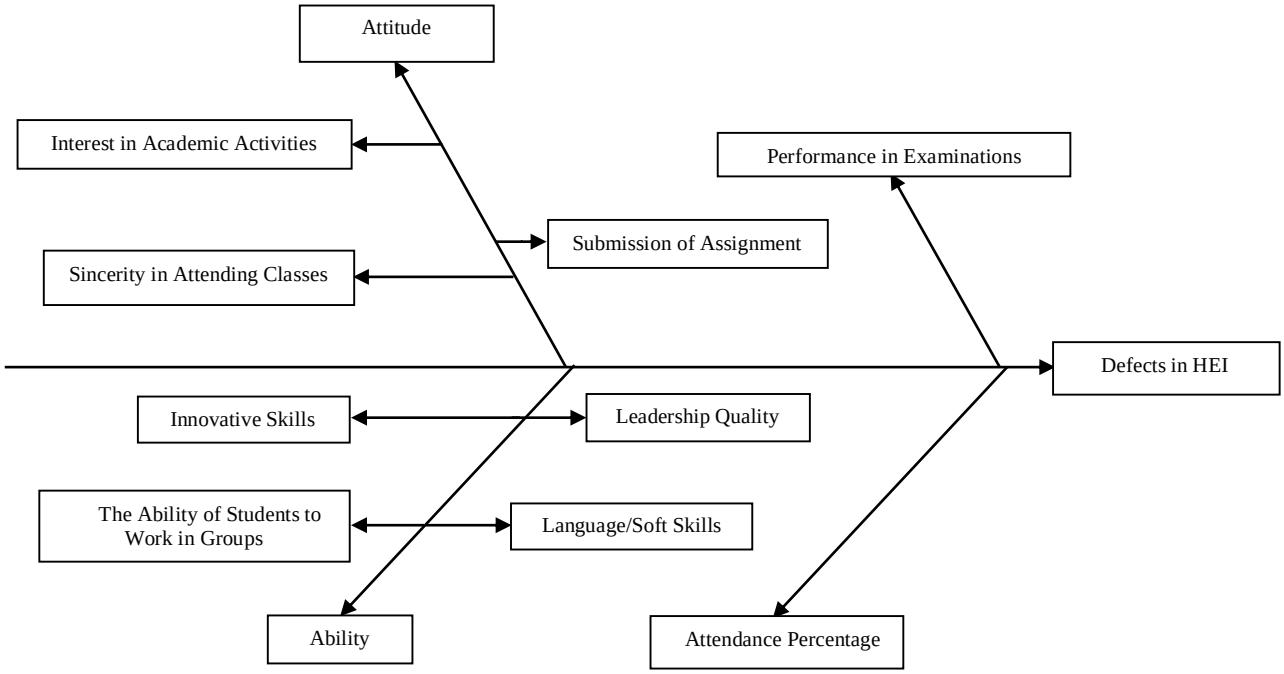

Fig. 4 Cause and effect diagram- factors affecting defects in HEIs

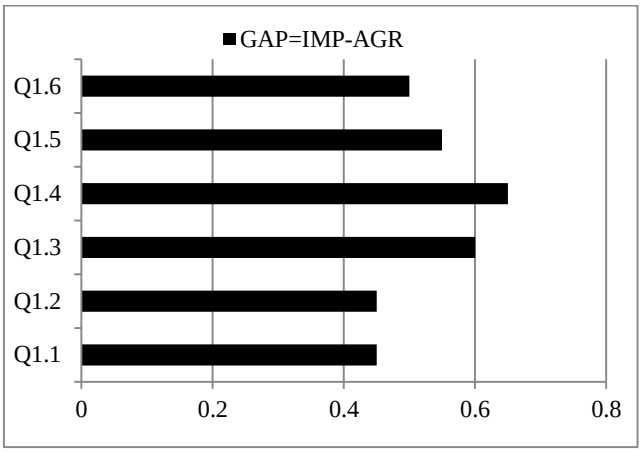

Fig. 5 Learning process- gap in resources

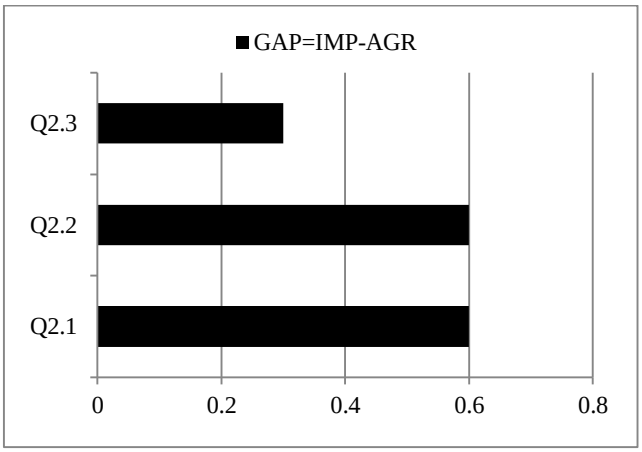

Fig. 6 Learning process -gap in course content

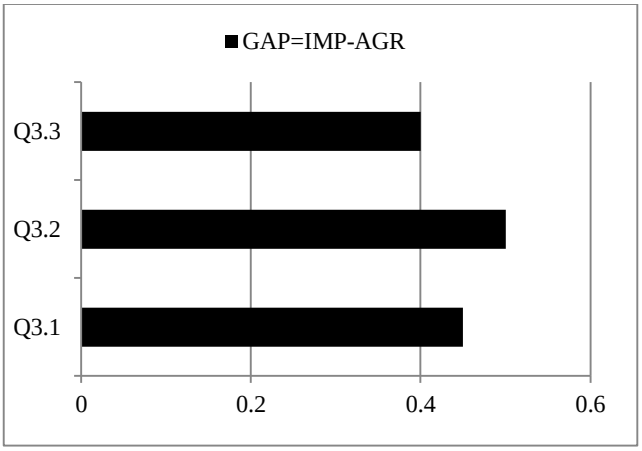

Fig. 7 Learning process -gap in delivery of courses

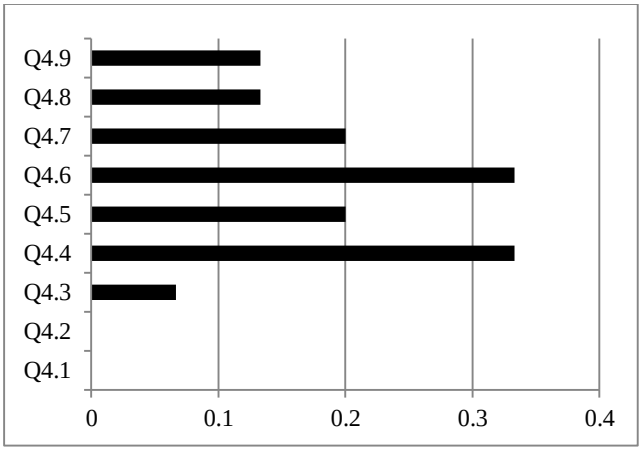

Fig. 8 Teaching process gap in faculty performance

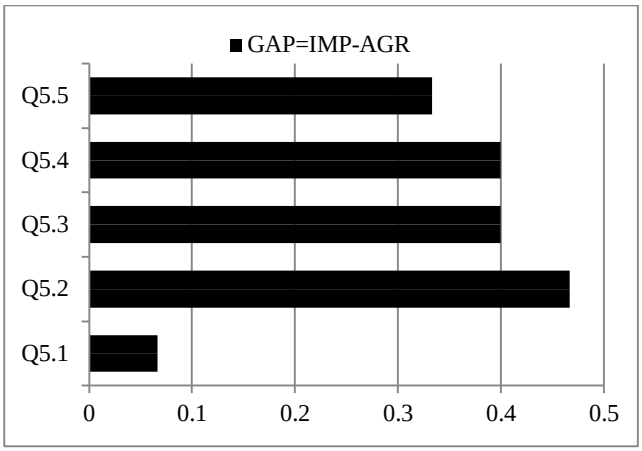

Fig. 9 Teaching process-gap in evaluation and feedback

These results show the importance of ensuring equipment in laboratories, e-journals, and national and international journals to improve student satisfaction. Also, while analyzing the learning process, more gaps were found in the course content (Q2.1) and subject delivery (Q3.2). Figure 6 shows the results of feedback on course content, and Figure 7 shows the results of feedback on the learning process concerning the delivery of courses. On analysis of the teaching process, it was found that the students were satisfied with the performance of the faculty, and they expect more academic support and timely advice from their teachers. Figure 8 shows the results of feedback on the teaching process concerning faculty performance. Figure 9 shows the results of evaluation and feedback. There was a gap between agreement and importance level regarding overall satisfaction as a student. The survey pointed out the specific areas and points of improvement in the teaching-learning process to ensure an excellent overall satisfaction level for the student.

Table 6. Failure mode effects analysis table-skill

Potential Failure Mode and Effects Analysis Sheet
(Process FMEA)

Process
For the Six Sigma Team
Prepared by
FMEA creation Date
Date of Last revision

	Potential Failure Mode	Potential Failure Effect	Potential Causes	Current Controls	Severity (SEV)	Occurrence (OCC)	Detection (DET)	RPN	Recommended Action	Responsibility and Due Date	Actions Taken	After Severity (SEV)	After Occurrence (OCC)	After Detection (DET)	After RPN
Language/ communication skills (improvement needed for defect1 and defect 5)	Failure to reproduce knowledge earned from courses	Low marks in end-semester examinations Less competency in placement opportunities	Non-attainment of writing and communication skills in the official language	No control	5	1	1	5	Conduct classes on writing and communication skills in the official language	Faculty handling the course	Conducted classes under placement cell	3	1	1	3
Leadership quality	Failure of managerial skills	Missing of gettogether attitude	Lack of managerial training	No control	2	1	1	2	Training in managerial skills	Faculty handling the course	Conducted training under placement cell	1	1	1	1
The ability of students to work in groups	Failure of managerial skills	Missing good social skills	Lack of managerial training	No control	2	1	1	2	Training in managerial skills	Faculty handling the course	Conducted training under placement cell	1	1	1	1
Innovative skills	Failure of managerial skills	Missing adaptability and creativity	Lack of training in advanced technology	No control	2	1	1	2	Training in managerial skills	Faculty handling the course	Conducted training under placement cell	1	1	1	1

Table 7. Failure mode effects analysis table-Attitude

Potential Failure Mode and Effects Analysis Sheet
(Process FMEA)

Process For Six Sigma Team
Prepared by
FMEA creation Date Date of Last revision

	Potential Failure Mode	Potential Failure Effect	Potential Causes	Current Controls	Severity (SEV)	Occurrence (OCC)	Detection (DET)	RPN	Recommended Action	Responsibility and Due Date	Actions Taken	After Severity (SEV)	After Occurrence(O	After Detection (DET)	After RPN
Sincerity in attending classes Interest in academic activities (Improvement needed for defect 1 and defect 6)	Absenteeism	1. Difficulty in understanding course 2. Ineligible to write end-semester exam	Not interested in academic activities	Publishing of attendance twice a week	10	1	1	10	1. Report to secondary stakeholders like parents daily by SMS 2. Contact the student regularly whenever he is absent 3. Counseling	Faculty in charge (The due date is before the next interval Exam.)	Reported to secondary stakeholder Contacted student regularly 3. Given Counseling	1	1	1	1
Submission of assignment (Improvement needed for defect 5)	Non-submission of assignment	1. Non-attainment of course outcome set by the University 2. Low internal marks	1. Attitude of late submission learned and practised from previous semesters of study	Recording in the faculty register	10	1	1	10	1. Contact the student one day before the due date and compel him to submit	Faculty in charge (The due the date is before the next Internal Exam.)	Contacted student and compelled him to submit	1	1	1	1
Internal examinations (Improvement needed for defects 1 to 8)	Failure due to non-attainment of Minimum marks	1. Non-attainment of course outcome set by the University 2. Low internal marks	1. Poor performance in the exam 2. Unprepared 3. Knowledge level 4. Writing skills	Publishing and Sending of results to parents	10	1	1	10	Continuous monitoring and improvement classes for knowledge improvement.	Faculty in charge (The due date is before the next interval Exam.)	Monitored the students till l the second internal examination	1	1	1	1

Table 8. Control plan

Process Steps	Control Mechanism	Measure / Metric	Criticality (HML)	Action is Taken If Problems Occur	Owner
Correcting of Defect 1	Improvement in Academic Performance and Absenteeism	Test1 Marks-40% Attendance-66%	H	Academic performance is to be improved by using the social media-based platform. Absenteeism is to be controlled.	Faculty
Correcting of Defect 2	Improvement in Academic Performance	Test1 Marks-25% Attendance-76%	H	Academic performance is to be improved by using the social media-based platform.	Faculty
Correcting of Defect 3	Improvement in Academic Performance	Test1 Marks-40% Attendance-80%	H	Academic performance is to be improved by using the social media-based platform.	Faculty
Correcting of Defect 4	Improvement in Academic Performance	Test1 Marks-30% Attendance 80%	H	Academic performance is to be improved by using the social media-based platform.	Faculty
Correcting of Defect 5	Improvement in Academic Performance Absenteeism	Test1 Marks-20% Attendance-76% Submission of Assignment-Nil	H	Academic performance and submission of assignments are to be improved by using the social media-based platform.	Faculty
Correcting of Defect6	Improvement in Academic Performance	Test1 Marks-30% Attendance-70%	H	Academic performance is to be improved by using social media-based platform. Absenteeism is to be controlled.	Faculty
Correcting of Defect 7	Improvement in Academic Performance	Test1 Marks-35% Attendance-80%	H	Academic performance is to be improved by using the social media-based platform.	Faculty
Correcting of Defect 8	Improvement in Academic Performance	Test1 Marks-25% Attendance-66%	H	Academic performance is to be improved by using the social media-based platform. Absenteeism is to be controlled.	Faculty
Students Satisfaction	Improvement in Customer Satisfaction	Voice of Primary Stakeholders	H	Student satisfaction surveys.	Project Team Leader
Faculty Satisfaction	Improvement of Faculty Satisfaction	Voice of Faculty	M	Faculty satisfaction surveys.	Project Team Leader

3.4. The Improve Phase

In the improvement phase, the project team developed an improvement plan by conducting a brainstorming session among the team members. To perform a risk assessment and identify the root causes of problems, an Failure Mode Effects Analysis (FMEA) table was constructed. The FMEA worksheet describes actions to be taken to reduce the Risk Priority Number (RPN) by considering the severity of the failure modes.

Table 6 shows the FMEA table constructed for the skill attribute, and Table 7 shows the FMEA table built for the attitude attribute. The crucial processes analyzed are internal examination performance, communication skills attainment, sincerity of students in attending classes, and assignment submission. The project was performed in a short period before the commencement of the second internal examination.

Improvements actions were taken for the students listed in the defect list within the specified period. After the improvement phase, the RPN of failure modes was reduced considerably.

3.5. The Control Phase

Based on the improvement plan for correcting the list of students as identified as defects, a control action was prepared to control and maintain the improvements.

A control plan will be a detailed guide for maintaining all of the changes implemented during the project [23]. Table 8 depicts the prepared control plan. The features of the control plan are detailed below.

- A Six Sigma cluster was constituted by connecting faculties handling similar courses. The cluster was headed by an experienced faculty and assisted by course experts in the related area as black belts to make corrective actions on the performance of defects.
- The team encouraged the students to utilize the course contents using a social media-based platform. The platform was available on the mobile phones of students. The students were encouraged to clarify their doubts and difficulties through this media. The method helped them to give valuable suggestions and feedback on clarity and understandability, of course.
- The social media-based platform can prepare the submission schedule and accept and regulate the submission of assignments at the right time. The scheduled publishing of attendance and sending of alerts of percentage attendance to secondary stakeholders such as parents will reduce student absenteeism.

To maintain the improvements, the owner specified in the control plan will take action if problems occur during the processes.

4. Results and Discussion

The integration of Six Sigma and European Fundamental Quality Management (EFQM) technique for continuous improvement is successfully conducted in one of the Mechanical Engineering courses. The data is collected, analyzed, and reviewed periodically to ensure “zero defects” in the delivery of courses. The effect of implementing Six Sigma DMAIC concerning the eight defects at the end of the second internal examination was measured.

The results indicated that all the students who were declared as a “defect’ and treated under the Six Sigma DMAIC methodology got passing marks in the second internal examination, making their defect count from 8 to 0. Thus, Six Sigma capability, such as ‘zero defect,’ can be obtained in examinations if Six Sigma DMAIC methodologies are applied at the right time. The absenteeism can be controlled by the project team’s regular monitoring of class hours.

The project team motivates the students to achieve better results in final examinations. The increase in the number of evaluations and feedback and its compliance resulted in more satisfaction in the face of stakeholders. The feedback collected from students as per EFQM helped the faculty to adjust their teaching speed of presentation.

The EFQM evaluation feedback system resulted in the improvement of clarity and understandability of courses. The working style of faculties was improved due to the two-phase monitoring. The continuous evaluation resulted in the improvement of the submission rate of assignments by the students.

The attendance percentage was significantly enhanced due to the periodic publishing of attendance after the feedback. The study was conducted particularly in one of the courses and resulted in considerable improvement of the sigma level after six months of continuous course improvement.

5. Conclusion

The positive results from evaluation and feedback systems prove that the Six Sigma DMAIC can successfully be integrated with the EFQM. This methodology can effectively be applied to teaching-learning. The significant advantage of the system is correcting mistakes at the earlier stages of the teaching-learning process.

The system also improves teachers’ flexibility as they can change themselves to attain better results. The methodology will enhance the satisfaction level of students in the course. The arrangement and structure of service sectors like HEI are very complex. The actions to be taken for the improvement of the process are also complex. The products of HEIs are the students undergoing graduate courses.

More attention is to be given to training the top management in the concepts of Six Sigma. Applying continuous improvement strategies in the teaching-learning process to all other courses can improve the institution's overall performance.

The continuous course improvement was applied to one course at one University. The study can produce more impact if the Six Sigma DMAIC methodology is applied to courses in other departments of HEIs. The proposed method can generally be used in any higher education institute, irrespective of the courses offered.

More qualitative and quantitative studies are required in the future to test integrating Six Sigma with other quality management systems and measure the satisfaction of different stakeholders of HEIs, such as employees, employers, and parents.

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References

[1] Sylvie Nadeau et al., "Lean, Six Sigma and Lean Six Sigma in Higher Education: A Review of Experiences around the World," *American Journal of Industrial and Business Management*, vol. 7, no. 5, pp. 591-603, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[2] Anete Petrusch, and Guilherme Luís Roehe Vaccaro, "Attributes Valued by Students in Higher Education Services: A Lean Perspective," *International Journal of Lean Six Sigma*, vol. 10, no. 4, pp. 862-882, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[3] P. Ramasubramanian, "Six Sigma in Educational Institutions," *International Journal of Engineering Practical Research*, vol. 1, no. 1, pp. 1-5, 2012. [Google Scholar] [Publisher Link]

[4] Carsten Svensson et al., "A Lean Six Sigma Program in Higher Education," *International Journal of Quality & Reliability Management*, vol. 32, no. 9, pp. 951-969, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[5] Thomas Pyzdek, *The Six Sigma Project Planner: A Step-by-Step Guide to Leading a Six Sigma Project through DMAIC*, McGraw Hill, New York, 2003. [Google Scholar] [Publisher Link]

[6] Jiju Antony et al., "Challenges in the Deployment of LSS in the Higher Education Sector: Viewpoints from Leading Academics and Practitioners," *International Journal of Productivity and Performance Management*, vol. 64, no. 6, pp. 893-899, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[7] Pavel Adina-Petruța, and Sârbu Roxana, "Integrating Six Sigma with Quality Management Systems for the Development and Continuous Improvement of Higher Education Institutions," *Procedia-Social and Behavioral Sciences*, vol. 143, pp. 643-648, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[8] L. Ramanan, M. Kumar, and K.P.V. Ramanakumar, "Six Sigma-DMAIC Framework for Enhancing Quality in Engineering Educational Institutions," *International Journal of Business and Management Invention*, vol. 3, no. 1, pp. 36-40, 2014. [Google Scholar] [Publisher Link]

[9] Gökhan Sontay, and Orhan Karamustafaoğlu, "A New Method for Science Teaching: 6-Sigma Method," *Journal of Education and Practice*, vol. 8, no. 32, pp. 13-19, 2017. [Google Scholar] [Publisher Link]

[10] S. Narayanamoorthy, "*Investigations on the Implementation of the Six Sigma Concept in Indian Engineering Colleges*," Shodhganga: A Reservoir of Indian Theses, Faculty of Mechanical Engineering, Anna University, 2013. [Google Scholar] [Publisher Link]

[11] M. Shoeibi, and E. Zahmatdoost, "The Role of Six Sigma in Improving the Quality of Higher Education Institutions," *The SIJ Transactions on Industrial, Financial & Business Management (IFBM)*, vol. 3, no. 6, pp. 93-98, 2015. [Google Scholar]

[12] Paula Y.K. Kwan, "Application of Total Quality Management in Education: Retrospect and Prospect," *International Journal of Educational Management*, vol. 10, no. 5, pp. 25-35, 1996. [CrossRef] [Google Scholar] [Publisher Link]

[13] Prabhakar Kaushik, and Dinesh Khanduja, "Utilising Six Sigma for Improving Pass Percentage of Students: A Technical Institute Case Study," *Educational Research and Reviews*, vol. 5, no. 9, pp. 471-483, 2010. [Google Scholar] [Publisher Link]

[14] Lee Harvey, and Diana Green, "Defining Quality," *Assessment and Evaluation in Higher Education*, vol. 18, no. 1, pp. 9-34, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[15] Jennie Oliver, Zachary Oliver, and Charles Chen, "Applying Lean Six Sigma to Grading Process Improvement," *International Journal of Lean Six Sigma*, vol. 10, no. 4, pp. 992-1017, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[16] Ahoo Shokraiefard, "*Continuous Quality Improvement in Higher Education - A Case Study in Engineering School of Boras University*," Thesis, University of Boras, pp. 1-40, 2011. [Google Scholar] [Publisher Link]

[17] Ali Erdoğan, and Hacer Canatan, "Literature Search Consisting of the Areas of Six Sigma's Usage," *Procedia - Social and Behavioral Sciences*, vol. 195, pp. 695-704, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[18] Sung H. Park, *Six Sigma for Quality and Productivity Promotion*, Asian Productivity Organization, pp. 1-218, 2003. [Google Scholar] [Publisher Link]

[19] Jiju Antony et al., "Readiness Factors for the Lean Six Sigma Journey in the Higher Education Sector," *International Journal of Productivity and Performance Management*, vol. 63, no. 2, pp. 257-264, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[20] Godson A. Tetteh, "Improving Learning Outcome Using Six Sigma Methodology," *Journal of International Education in Business*, vol. 8, no. 1, pp. 18-36, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[21] Jacqueline Douglas, Jiju Antony, and Alexander Douglas, "Waste Identification and Elimination in HEIs: The Role of Lean Thinking," *International Journal of Quality & Reliability Management*, vol. 32, no. 9, pp. 970-981, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[22] Ingo Kregel, "Kaizen in University Teaching: Continuous Course Improvement," *International Journal of Lean Six Sigma*, vol. 10, no. 4, pp. 975-991, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[23] Jennifer Wheeler-Webb, and Sandra L. Furterer, "A Lean Six Sigma Approach for Improving University Campus Office Moves," *International Journal of Lean Six Sigma*, vol. 10, no. 4, pp. 928-947, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[24] Jing Lu, Chad Laux, and Jiju Antony, "Lean Six Sigma Leadership in Higher Education Institutions," *International Journal of Productivity and Performance Management*, vol. 66, no. 5, pp. 638-650, 2017. [CrossRef] [Google Scholar] [Publisher Link]

Appendix 1

Table 9. Students satisfaction feedback form for teaching learning process

Teaching Learning Process-Students Satisfaction Feedback Form											
Sl. No		Agreement					Importance				
		Disagree very much	Disagree	Agree slightly	Agree	Agree very much	Disagree very much	Dis agree	Agree slightly	Agree	Agree very much
1	**Learning Process-Resources**										
1.1	I have been informed about the importance of Textbook										
1.2	Sufficient library books are available for making my studies more effective.										
1.3	e-journals and other IT resources are available for my assistance										
1.4	National and international journals are available for reference and knowledge enhancement										
1.5	The equipments and other infrastructural facilities are available and accessible for practical development in the subject										
1.6	My knowledge has been improved due to sufficient availability of resources										
2	**Learning Process-Course Content**										
2.1	I am satisfied with the contents of the subject										
2.2	I am satisfied with the knowledge received from the subject content										
2.3	The total hours for the subject per week is sufficient										
3	**Learning Process Delivery of Courses**										
3.1	I can explore ideas confidently										
3.2	The learning of the subject was so easy due to proper subject delivery										
3.3	I have received sufficient practical knowledge on the subject										
4	**Teaching Process-Faculty**										
4.1	The clarity and understandability of explanation of the subject by the faculty is excellent										
4.2	The interest of the faculty in handling subjects is excellent										
4.3	The behavior of the faculty is excellent										

4.4	I am satisfied with the academic support received										
4.5	The willingness of the faculty to help at any time is excellent										
4.6	I have received sufficient and timely advice										
4.7	I can independently study lessons due to the support and advice received from my faculty										
4.8	I have received proper respect from my faculty										
4.9	The work schedule on the subject as per the timetable is conducted efficiently										
5	**Teaching Process-Evaluation And Feedback System**										
5.1	I have been informed about the minimum marks and credentials required for a pass										
5.2	I have been informed about the scheme of giving marks to answers in a question paper										
5.3	The system of evaluation and assessment is excellent										
5.4	The feedback system on the subject is prompt										
5.5	The clarity and understandability of the assessment system is excellent due to the feedback										
6	**Overall Satisfaction**										

Appendix 2

Table 10. Learning process -resources

Survey Question No.	Question	Agreement (AGR)	Importance (IMP)	GAP=IMP-AGR
Q1.1	I have been informed about the importance of Textbook	3.15	3.6	0.45
Q1.2	Sufficient library books are available for making my studies more effective.	2.9	3.35	0.45
Q1.3	e-journals and other IT resources are available for my assistance	2.65	3.25	0.6
Q1.4	National and international journals are available for reference and knowledge enhancement	2.3	2.95	0.65
Q1.5	The equipments and other infrastructural facilities are available and accessible for practical development in the subject	2.6	3.15	0.55
Q1.6	My knowledge has been improved due to sufficient	2.6	3.1	0.5

Table 11. Learning process -course content

Survey Question No.	Question	Agreement (AGR)	Importance (IMP)	GAP=IMP-AGR
Q2.1	I am satisfied with the contents of the subject	2.7	3.3	0.6
Q2.2	I am satisfied with the knowledge received from the subject content	2.5	3.1	0.6
Q2.3	The total hours for the subject per week is sufficient	3	3.3	0.3

Table 12. Learning process -delivery of courses

Survey Question No.	Question	Agreement (AGR)	Importance (IMP)	GAP=IMP-AGR
Q3.1	I can explore ideas confidently	2.85	3.3	0.45
Q3.2	The learning of the subject was so easy due to proper subject delivery	2.65	3.15	0.5
Q3.3	I have received sufficient practical knowledge on the subject	2.7	3.1	0.4

Table 13. Teaching process -faculty performance

Survey Question No.	Question	Agreement (AGR)	Importance (IMP)	GAP=IMP-AGR
Q4.1	The clarity and understandability of explanation of the subject by the faculty is excellent	2.933	2.93333	0
Q4.2	The interest of the faculty in handling subjects is excellent	3.133	2.93333	-0.2
Q4.3	The behaviour of the faculty is excellent	3.067	3.13333	0.0666667
Q4.4	I am satisfied with the academic support received	2.533	2.86667	0.3333333
Q4.5	The willingness of the faculty to help at any time is excellent	3.267	3.46667	0.2
Q4.6	I have received sufficient and timely advice	2.733	3.06667	0.3333333
Q4.7	I can independently study lessons due to the support and advice received from my faculty	2.8	3	0.2
Q4.8	I have received proper respect from my faculty	3.467	3.6	0.1333333
Q4.9	The work schedule on the subject as per the timetable is conducted efficiently	2.933	3.06667	0.1333333

Table 14. Teaching process -evaluation and feedback system

Survey Question No.	Question	Agreement (AGR)	Importance (IMP)	GAP= IMP=AGR
Q5.1	I have been informed about the minimum marks and credentials required for a pass	3.2	3.2667	0.0666667
Q5.2	I have been informed about the scheme of giving marks to answers in a question paper	2.733	3.2	0.4666667
Q5.3	The system of evaluation and assessment is excellent	3.267	3.66667	0.4
Q5.4	The feedback system on the subject is prompt	2.733	3.13333	0.4
Q5.5	The Clarity and understandability of the assesment system is excellent due to the feedback	3.133	3.466667	0.3333333
Q5.6	I have been informed about the minimum marks and credentials required for a pass	3.2	3.26667	0.0666667
Q5.7	I have been informed about the scheme of giving marks to answers in a question paper	2.733	3.2	0.4666667
Q5.8	The System of evaluation and assessment is excellent	3.267	3.66667	0.4
Q5.9	The work schedule on the subject as per the timetable is conducted efficiently	2.933	3.06667	0.1333333