Implementation of Six Sigma training and certification at the university level

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Abstract. Six Sigma is a continuous improvement tool intended to reduce costs and improve quality by reducing defects to extremely low levels. Although Six Sigma initiatives have generated billions of dollars of documented savings and employers seek trained candidates, certified Six Sigma training at the university level is relatively scarce. To partially address this shortcoming, this paper describes the establishment, implementation, and accreditation of a Six Sigma technical elective within University of Maine's Mechanical Engineering Technology program. Specific topics include a characterization of the student cohort, curriculum, startup expenses, accreditation, certification of students, and the envisioned expansion of Six Sigma courses.

1. Introduction

Six Sigma is a continuous improvement methodology intended to increase profitability by reducing defects to extremely low levels, defined here as 3.4 defects per million opportunities (DPMO). To put 3.4 DPMO in perspective, a 250-page book with 300-words-per-page and 5-characters-per-word would have approximately 1.3 incorrect characters throughout the entire 250 pages. The name Six Sigma is derived from the desire to have the mean of a process be six standard deviations, or sigmas, from the nearest specification limit, which when accounting for long term variation, results in 3.4 DPMOs [1]. A graphical realization of a standard normal distribution (*i.e.*, process mean, $\bar{x}$, of zero, and standard deviation, σ, of one) centered six standard deviations from the nearest specification limit is shown in Figure 1. In Figure 1, the solid red line represents the response (*i.e.*, output) of the process, and the vertical axis represents the probability of a response at the given value shown on the horizontal axis. Customer requirements, expressed in terms of a lower specification limit (LSL) and an upper specification limit (USL), are shown as dashed vertical lines at -6σ and +6σ, respectively.

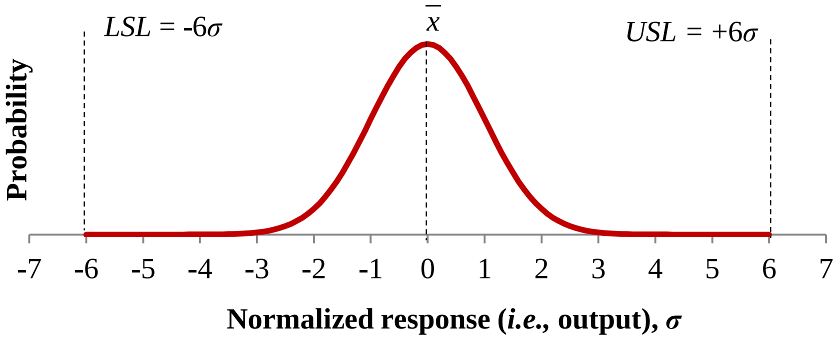

Figure 1. Standard normal distribution (solid red curve) shown with a -6σ lower specification limit (LSL) and a +6σ upper specification limit (*USL*).

As stated by Harry [2], the average American company operates at a 4 sigma level, *i.e.*, the process mean is approximately 4 standard deviations from the nearest specification limit, resulting in products and services having approximately 6,210 DPMO, or approximately *1,800 times* more defects than a six sigma process. To improve quality and reduce defects, the Six Sigma methodology incorporates a systematic, five-step process consisting of Define, Measure, Analyze, Improve, and Control (DMAIC).

Although first introduced by Bill Smith of Motorola in 1986 [1], Six Sigma relies upon proven statistical, operational, manufacturing, and quality techniques and best practices dating to the early 19th century [3]. Several significant contributions to Six Sigma are shown in the timeline in Figure 2 [1], [4]–[8]. As shown in Figure 2, the financial impact of Six Sigma is significant, with Motorola and GE claiming $16 billion and $12 billion, respectively, in savings during their first five years of implementation [6]. In 2002, George [8] combined Six Sigma with Lean Manufacturing, a continuous improvement methodology seeking to increase a company's profits by increasing the rate at which value is added to a product or service by reducing waste, or *muda*. The seven classic forms of *muda* are defects, overproduction, transportation, waiting, inventory, motion, and (over)processing.

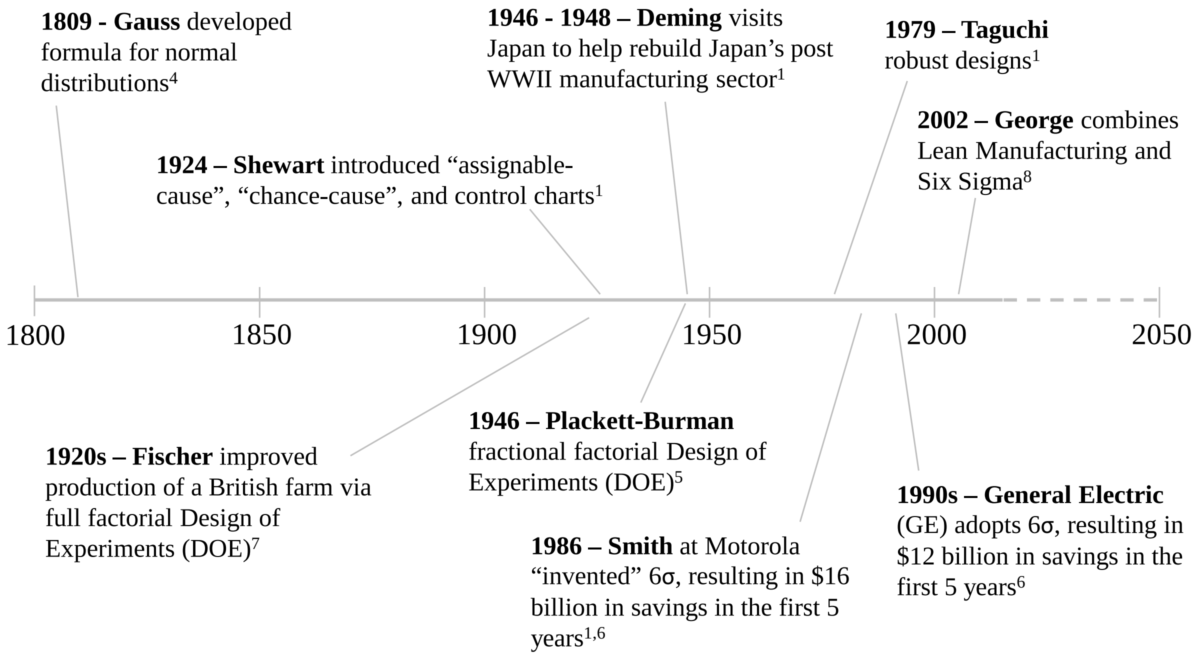

Figure 2. Partial history of Six Sigma.

Six Sigma organizations typically have four levels, or "Belts," indicating an individual's experience, knowledge, and availability. Individuals possessing the least amount of Six Sigma knowledge and experience are typically referred to as "Yellow Belts" and are part-time process improvement team members who have a basic knowledge in the DMAIC model and associated tools. With increased knowledge and responsibilities, individuals possessing "Green Belts" are part-time process improvement team members who work on projects on an ad-hoc basis. Green Belts are trained and knowledgeable in the DMAIC process, but have insufficient experience to independently lead projects. After achieving a sufficient level of experience, individuals with Green Belts may obtain Black Belts and work full-time on process improvement projects. A Black Belt is typically responsible for training Green Belts and completing five to six projects a year, each project saving approximately $175,000 [2]. Pending further training, Black Belts may become Master Black Belts, who are responsible for developing an organization process improvement strategy and training Black Belts.

Despite Six Sigma's established financial successes and historical basis, a 2003 survey of 87,500 individuals yielding 2,870 responses indicated that fewer than 22% of companies had some sort of Six Sigma program [9]. Of the companies that self-reported to have Six Sigma program in place, 90% were companies with more than 2,000 employees [9]. Results from a different 2003 survey of 90,000 individuals yielding 2,577 responses indicated similar results, namely, a relatively small number of companies had implemented Six Sigma programs and that relatively small companies with fewer than 500 employees rarely implemented Six Sigma programs [10]. Further, Dusharme [10] stated that small companies struggled to implement Six Sigma partly due to training costs.

To partially address this issue and a lack of Six Sigma training within central Maine, the University of Maine introduced MET 320, a Six Sigma Green Belt course, in the Fall 2016 semester. Although the course's curriculum primarily addresses Six Sigma, Lean Manufacturing topics are included to provide students with a well-rounded continuous improvement background. The remainder of this paper details the student cohort, curriculum, startup expenses, accreditation, certification of students, and the envisioned expansion in Sections II through VII, respectively.

2. Student cohort

The Fall 2016 student cohort consisted of 26 students, of which 23 students were male, and 3 students were female. Twenty-one students were Mechanical Engineering Technology (MET) majors, 4 students were Chemical Engineering (CHE) majors, and 1 student was a Bioengineering (BEN) major. Only students from MET, CHE, and BEN majors were accepted for the first offering of MET 320. MET students registered knowing that MET 320 fulfilled 3 technical elective credits toward their degree program; CHE and BEN students registered unsure if MET 320 would apply to their CHE and BEN degree programs. Thus, it was reasonable that more MET students than CHE and BEN students registered for the course.

Although all 26 students satisfactorily completed the Calculus II pre-requisite prior to enrollment in MET 320, the math requirements for the CHE, BEN, and MET programs were different. Whereas the CHE and BEN programs required Calculus I, II, and III, Differential Equations, and a statistics course [11], [12], the MET program required Calculus I and II, and Differential Equations [13]. Because Six Sigma relies upon statistical analyses, the lack of a statistics pre-requisite created a student cohort with varying foundational knowledge.

3. Curriculum and curriculum deployment

The curriculum was delivered via four channels: independent assignments, in-class lectures, in-class hands-on learning activities, and sponsored projects. In-class lecture and hands-on learning were completed within 39 contact hours delivered over 13 weeks, at 3 contact hours per week on Monday evenings from 5:30 to 8:30 PM. The one-day-per-week, 3-hour-long evening meeting time was chosen to minimize time conflicts of students from multiple engineering programs.

3.1 Independent assignments

The independent assignments consisted of independently reading Pande, Neumann, and Cavanaugh [14] and Quality Council of Indiana's Certified Six Sigma Green Belt (CSSGB) Primer [15], reviewing George and Maxey [16], and listening to an NPR podcast [17] describing the successes and failures of New United Motor Manufacturing, Inc. (NUMMI), an automotive manufacturing facility joint venture by General Motors and Toyota. Students were also encouraged to work sample problems within the CSSGB Primer [15] and compare their answers to the solutions given in Quality Council of Indiana's CSSGB Solutions [18], a recommended text. Student comprehension of the weekly reading assignments was assessed via short in-class quizzes administered every week.

3.2 In-class lectures

Due to the large volume of material, in-class lectures were intended to reinforce and strengthen concepts encountered by students during their independent reading. Lectures also including example problems solved via hand calculations or Minitab v17, a statistical analysis program [19]. A list of Lean Manufacturing and Six Sigma topics covered during in-class lecture or hands-on learning activities is shown in Table 1. The interested reader is directed to the course texts [14]–[16], [18] for more information on each subject.

Table 1. Lean Manufacturing and Six Sigma topics by subject area.

Subject area	**Topics**
Lean Manufacturing	7 forms of *muda*, continuous flow manufacturing, value stream mapping, *kanbans*, value added and non-value added activities, visual factory, and 5S
Define	Project selection, Voice of Customer (VOC), project charter, Kano analysis, Supplier Input Process Output Customer (SIPOC)
Measure	Types of data, defects per million opportunities (DPMO), Gage Repeatability and Reproducibility (Gage R&R), measurement systems analysis (MSA), accuracy versus precision, rolled through yield (RTY), confidence intervals, α risk, power, β risk, sample size, Z-distribution tables, t-distribution tables, degrees of freedom, and capability studies
Analyze	Pareto analysis, correlation, linear and non-linear regression, hypothesis testing, t-tests, analysis of variance (ANOVA), and Ishikawa diagrams
Improve	Full and fractional factorial design of experiments
Control	Statistical Process Control (SPC)

3.3 Hands-on learning activities

In addition to in-class lectures, three in-class hands-on learning activities were introduced to develop intuition regarding the subjects. The first hands-on learning activity involved the simulated factory activity detailed in Section 3.3.1 below and was conducted after reinforcing the students' theoretical understanding via a "7 forms of *muda*" lecture. The two remaining hands-on learning activities involved the Gage R&R of a statapult measurement system and regression analysis of statapult data, both of which were analyzed via Minitab 17 and conducted after reinforcing students' theoretical understanding via activity-specific in-class lectures. Each in-class hands-on learning activity required between 1 to 1.5 hours to conduct.

3.3.1 Example hands-on learning activity: Factory simulation

The first hands-on learning activity involved a simulated factory in which three teams of nine members – two teams of 9 students each and one team of 8 students and one auditing faculty member – competed to build Lego$^{\text{TM}}$ see-saws, similar to that shown in Figure 3. Each see-saw consisted of 13 parts, as described in Table 2.

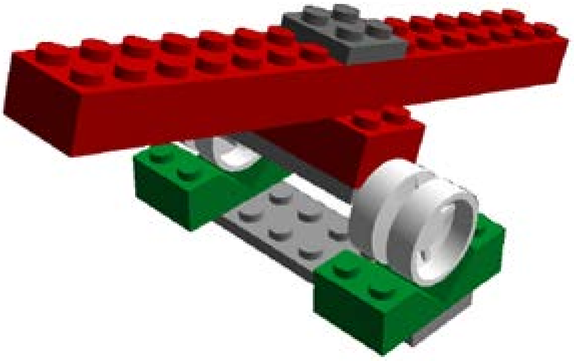

Figure 3. Lego™ see-saw used within factory simulation activity.

Table 2. See-saw bill of material.

Part #	QTY	Subassembly	Description	Color
1	4	Base	2 × 2 / 45°	Specified by customer (e.g., red, black, green)
2	1	Base	2 × 8 block	Gray
3	1	Lever	2 × 2 plate	Gray
4	2	Lever	2 × 8 brick	Specified by customer (e.g., red, blue, green)
5	1	Lever	2 × 4 brick	Specified by customer (e.g., red, blue green)
6	2	Lever	2 × 4 axle	Gray
7	2	Lever	hub	White

The factory simulation consisted of five rounds during which each team produced the see-saws requested by the Customer (*i.e.*, the instructor). Between sequential rounds, each team of students decided how many employees, at a rate of $1/employee/round, and what job positions were to be utilized during the next round. Employee positions include:

- **Material handler** - retrieved raw materials from supply depot, delivered see-saws to the Customer
- **Operator** - assembled see-saws from raw materials
- **Quality control** - inspected incoming raw materials and out-going see-saws
- **Manager** - managed the factory during operations and could perform any tasks of the other three positions. Within any given round, there was at most 1 manager per factory.

During the first round, each of the nine team members per team had to assume one of the four positions above.

Each 3-minute round began with the Customer placing an order for a number of see-saws with a given color combination (*e.g.*, 4 see-saws with green levers and red bases for $2/each). Although each round started with a single Customer order, the Customer could and did place more than one order within a given round. Each team of students then procured raw materials, assembled see-saws, and delivered the assembled see-saws to the Customer on a styrofoam shipping container. Depending upon the quality and timeliness of each delivered see-saw, one of two outcomes were possible:

1. If the as-requested see-saw was delivered within the allotted time, the team of students received the full sales price for the see-saw; or
2. If the see-saw failed to meet the specifications required by the Customer, the see-saw was returned to the factory for re-work.

After each round, any raw materials received by a team but not delivered to the Customer costs that team of students \$0.05/piece.

At the beginning of the first round, raw materials were sorted by assembly color, but not by shape, within plastic bins near the center of the class room. Each factory was located approximately 20 feet from the center of the class room. At the end of the first 3-minute-long round, one team lost \$2.75 and completed 4 see-saws. The two remaining teams lost \$11.40 and failed to deliver a single see-saw. Teams were then given 5 to 8 minutes between rounds to brain storm and implement improvement strategies. By the end of the 5th round, all teams produced in excess of 15 see-saws with 3 or fewer employees per team, resulting in profits in excess of \$27 per team. Although each team implemented the solutions in different sequences, substantial improvements to the production systems were achieved by reducing transportation distances from the raw material storage location to the factory, reducing employee wait times, reducing the sorting of parts by having the raw materials delivered as kits, and reducing the motion of students within the team. Through this exercise, students gained an intuitive sense why lean manufacturing systems are important to the profitability of a business.

3.4 Sponsored projects

Sponsored projects provided an opportunity for students to engage with local industry and work on real problems. From a list of potential project ideas solicited from industry, students rank-ordered their top three projects. The instructor then matched students with projects based upon the students' rank-ordering and anticipated level of effort per project, resulting in six teams of 3 to 5 students per team. The six projects selected during the Fall 2016 semester are shown in Table 3. Students were allotted approximately 8 weeks to complete their projects.

Table 3. Sponsored projects.

Industry	Project description	Key tools
Thermoforming	Reduce mold change times	Single Minute Exchange of Dies (SMED), and spaghetti diagrams
Metal machining	Recommend and implement a work cell for continuous flow manufacture of a new product	continuous flow manufacturing, kanbans, standard work, identifying key process outputs variables
Health and beauty	Reduce the time required to fill health and beauty products	root cause analysis, continuous flow manufacturing, capability studies, DMAIC
Chemical processing	Increase the yield of an extraction process	root cause analysis, regression analysis
Power generation	Determine and minimize the variation of force required to press-fit a pin	Gage R&R, capability studies
Mechanical testing laboratory	Characterize precision of load frames; Reduce the time associated with setting up load frames	Gage R&R, 5S

4. Costs associated with Six Sigma course

The direct costs to implement a Six Sigma course as described in this paper for 26 students are classified by equipment, course development, and professional development in Table 4. For smaller or larger class sizes, the statapult and statapult accessories costs can be scaled by the number of 4-person teams within the class. The direct costs stated in Table 4 do not include requisite Six Sigma Black Belt experience and training of the instructor. Besides the consumables and annual Minitab student licenses, all costs are one-time costs.

Table 4. Direct costs associated with Six Sigma course.

Classification	QTY	Description	Costs (USD)
Equipment	1	Factory simulation (3 teams)	$ 600
Equipment	7	Statapults (1 statapult per 4 students)	$ 1,400
Equipment	1	Statapult accessories (balls, tape measures, bar clamps, storage containers)	$ 500
Equipment	1	Consumables (aluminum foil, bubble wrap, tape)	$ 25
Software	35	Annual Minitab student licenses	$ 1,500
Course Development	1	Texts and reference material	$ 600
Professional Development	1	ASQ Six Sigma Black Belt examination fee for ASQ members	$ 388
Total			$ 5,013

5. Six Sigma certifying and accrediting bodies

Unlike the engineering field in which Professional Engineers are licensed by state boards and all applicants take Fundamentals of Engineering and Professional Engineers exams administered by National Council of Examiners for Engineering and Surveying (NCEES), Six Sigma certification is an ad-hoc network of individual certifying bodies (*e.g.*, private firms, Universities) issuing certificates unique to that certifying body. For example, the requirements for two certifying bodies – the American Society for Quality (ASQ) and the International Association for Six Sigma Certification (IASSC) – are shown in Table 5. As shown in Table 5, the training, exam length and duration, required experience, and costs vary greatly. For example, Green Belt certification via IASSC requires neither in-class training nor work experience, whereas Green Belt certification via ASQ requires a minimum of 3 years work experience, but no formal training. In contrast to the examination-based certificates offered by IASSC and ASQ, multiple certification bodies teach courses and offer certificates. For example, the Georgia Institute of Technology offers a Lean Six Sigma Green Belt certificate after completing 40 contact hours of training for $3,950 and a Lean Six Sigma Black Belt certificate after completing an additional 56 hours of training for $6,050 [24]. The lack of standardized certification requirements is problematic for employers trying to compare multiple Six Sigma certified candidates, people wishing to be trained in Six Sigma, and certifying bodies.

Table 5. Comparison of Green Belt and Black Belt certification requirements for IASSC and ASQ.

Certificate		**IASSC [20]**	**ASQ[1] [21]–[23]**
Green Belt	Training	None	None
	Exam	100 question, 3 hour	100 questions, 4 hour
	Experience	None	3 years of work experience
	Costs	$295	$288 / $438
Black Belt	Training	No in-class training	No in-class training
	Exam	150 questions, 4 hours	150 questions, 4 hours
	Experience	None	2 projects[2]
	Costs	$395	$388 / $538

[1] Listed exam fees are for ASQ members / non-ASQ members.

[2] 2 projects <u>*or*</u> 1 project and 3 years of work experience

To address the problem, the Council for Six Sigma Certification (CSSC) has established minimum requirements for accrediting Six Sigma certificate granting bodies. CSSC accredits certificate-granting programs at the Yellow Belt, Green Belt, Black Belt, and Master Black Belt levels, and has accredited a total of 52 universities and 24 non-university certifying bodies in North America as of October 2016 [25]. Details of the accreditation requirements are given in Table 6. Accreditation entails completing a questionnaire, which is reviewed by CSSC for compliance with CSSC's accreditation requirements. In addition to the requirements listed in Table 6, the CSSC requests information as to how the certificate-granting body will ensure confidential data will be kept confidential. Although IASSC accredits training programs, IASSC does not accredit certification bodies [20]. Thus IASSC was not included in this analysis of accrediting bodies.

Table 6. CSSC accreditation requirements for Black Belt and Green Belt certifying bodies [25].

Belt Level	**Requirements for accreditation**
Green Belt	35 hours of training (in-person, online, or mixed) CSSC-specified body of knowledge Instructor must be a Black Belt or a Master Black Belt Written (physical or electronic) exam No project experience required Fee determined by certificate-granting body
Black Belt	95 hours of training (in-person, online, or mixed) CSSC-specified body of knowledge Instructor must be a Master Black Belt Written (physical or electronic) exam Completion of 1 project Fee determined by certificate-granting body

Based upon CSSC being the only accrediting body identified that accredited certifying bodies, the University of Maine applied for accreditation by CSSC. Accreditation required the completion of a questionnaire and University of Maine's agreement to the requirements specified by CSSC. Based upon the CSSC's requirements, the University of Maine, College of Engineering will issue non-expiring Six Sigma Green Belt certificates with unique certification numbers. The unique certification numbers will be traceable to individuals and will be maintained via a secured database, which can be accessed by university staff should a 3rd party request validation of a Six Sigma Green Belt certificate.

6. Certification of Six Sigma Green Belts at University of Maine

In addition to earning degree-satisfying credits, students may earn a University of Maine, College of Engineering "Six Sigma Green Belt Certificate," which is decoupled from the course grade. For example, it is possible to earn an "A" in the course without earning a certificate. Furthermore, it is possible, although unlikely, to earn a certificate while earning an "F" in the course.

Certification of Six Sigma Green Belts at the University of Maine rests upon four requirements. First, students must be present for a minimum of 35 contact hours during the semester. Second, students must successfully complete a sponsored project, with successful completion determined by the instructor and the project's sponsor. Third, students must earn at least 75% on a 100-question, 4-hour-long final exam. MET 320 students not opting for the SSGB Certificate sit for a 50-question, 2-hour-long final exam instead of the 100-question, 4-hour-long final exam taken by Certificate seeking students. Fourth, students must conduct themselves in a professional manner within the classroom and during sponsor interactions.

7. Lessons learned

The first offering of this course yielded learnings that will be applied to future MET320 offerings at the University of Maine. First, the students from multiple majors tended to form cliques based upon their entering peer groups. Mid-way through the semester, in-class groups were assigned by the instructor to intentionally separate clique members. In future semesters, in-class work groups will be assigned earlier in the semester to reduce or eliminate the barriers between student cliques sooner. Second, projects were kicked off in the first week of October, or approximately 6 weeks into the semester. Although the students had a reasonable level of knowledge to start interacting with sponsors at 6 weeks, this schedule interfered with the instructor's kick-off meetings for capstone design, another project-based course. Third, classes will be taught on Tuesday evening instead of Monday evening in order to avoid a university holiday, thus increasing the total contact hours to 42. Fourth, independent assignments will be restructured to reduce the amount of reading and increase the problem solving. Due to the students' varying statistics foundational knowledge, problem solving will be shifted to independent assignments to allow students to work problems at their own pace.

In addition to the learnings listed above, it is suggested that any university interested in teaching Six Sigma to undergraduate engineering students consider the following. First, it is important that the instructor have requisite knowledge and certification in Six Sigma. Beyond providing a better classroom learning environment, the CSSC requires that an instructor be knowledgeable and certified in Six Sigma. Second, the institution should survey the local industrial base to determine their needs and if Six Sigma is already being taught. Although small to medium companies often seek candidates with Six Sigma skill sets, large companies may not express a preference due to in-house Six Sigma training programs.

8. Summary and next steps

The University of Maine implemented a Six Sigma course in Fall 2016 with an optional Six Sigma Green Belt Certificate, which was accredited by the Council of Six Sigma Certification. Twenty-six students from three majors – Mechanical Engineering Technology, Chemical Engineering, and Bioengineering – registered for and will complete the course. The equipment, software, texts, and professional examinations costs were approximately $5,000, of which $3,500 were one-time costs and $1,500 were annual costs due to software licensing. Because the initial costs do not include the time and expense to train an instructor with the requisite knowledge and experience, the costs to implement the same program with an un-trained instructor would be substantially greater.

Given the strong student and employer interest in Six Sigma and continuous improvement, it is envisioned that future Six Sigma Green Belt courses will allow for: (1) larger class sizes, (2) students from all engineering majors, and (3) continuing education students from local industry. Additionally, it is envisioned that Six Sigma Green Belt students will, after completely several successful years in industry, return to the University of Maine for Six Sigma Black Belt training and certification, which will likely commence in or around 2020.

9. Acknowledgements

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