



## **Program Assessment Using Six Sigma Green Belt Certification Requirements**

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## **Abstract**

The Six Sigma system is widely used in industry to implement quality systems. It is a formal application of theory and practice to make better business decisions about design and manufacturing. Given the applied nature of the methods, a certification system has grown to endorse professionals that have received the training, applied the knowledge, and demonstrated results. One such example is the American Society for Quality (ASQ) Certified Six Sigma Green Belt (CSSGB) <sup>1</sup>. Naturally there has been interest in greater recognition of the standard from academia. The common response is that academia already prepares graduates with the needed knowledge. This paper outlines a brief study of the differences between an undergraduate manufacturing engineering curriculum and the certification. The results indicate that there are opportunities that could be considered for both academia and industry.

## **1. Introduction**

Manufacturing oriented programs shape industrial practices through educated graduates. In turn manufacturing educators look to practice for opportunities to refine and improve curriculum. Generally academic programs are the source of formal curriculum and assessment. Occasionally industry develops certification standards with a practical focus on applied theoretical knowledge. The majority of these certifications focus on problems shared by most manufacturers. Popular certification subjects include project management, manufacturing efficiency, and manufacturing quality.

The Six Sigma body of knowledge was originally developed by Motorola in 1986 <sup>2</sup>. It addressed manufacturing quality issues by integrating statistical tools with engineering and management practices. The certification process is based on increasingly difficult training and application of the principles. As professionals gain expertise they are awarded levels that include Yellow, Green, Black Belts, eventually earning the the Champion designation. Reviewing the curriculum for this program shows a great deal of traditional academic content integrated with business practices. In short, much of the standard manufacturing engineering academic content is in the certification. But, the organization of the standard is not well aligned with academic subjects. If anything the Six Sigma content appears as curriculum threads, as opposed to course sequences.

Industry and academic discussions are often hampered by different interpretations and views of manufacturing engineering knowledge. The Six Sigma certification standard provides a basis for communication. The key areas of the standard are Define, Measure, Analyze, Improve, and Control. This paper maps a manufacturing engineering program to the Six Sigma green belt standard. The map shows that programs generally deliver essential statistical methods and content. Other topics in the standard, such as ‘Piloting your solution’, are more suited to experiential activities in laboratories and projects. The outcome of the paper is an indication of how the standard manufacturing curriculum supports the Six Sigma standard. In addition, the paper will highlight aspects of the standard that do not require the addition of new courses but can enhance traditional topic coverage.

## 2. Six Sigma Green Belt Body of Knowledge

The topics listed below are summarized from the American Society for Quality Body of Knowledge for the Six Sigma Green Belt certification <sup>1</sup>. The document also lists a number of questions, indicating a relative weighting of topic importance. For the green belt certification the define and measure phases are emphasized. A cursory review of the topic list reveals many topics normally included in Manufacturing Engineering and Technology programs. The body of knowledge clearly includes theoretical elements, such as statistics, that are core to most undergraduate programs. Other elements are emphasized through projects and laboratory experiences including teamwork and data collection. Additional details can be found on the ASQ website (<http://www.asq.org>).

- I. Overview: Six Sigma and the Organization (13 Questions)
  - A. Six sigma and organizational goals
  - B. Lean principles in the organization
  - C. Design for six sigma (DFSS) methodologies
- II. Define Phase (23 Questions)
  - A. Project identification
  - B. Voice of the customer (VOC)
  - C. Project management basics
  - D. Management and planning tools
  - E. Business results for projects
  - F. Team dynamics and performance
- III. Measure Phase (23 Questions)
  - A. Process analysis and documentation
  - B. Probability and statistics
  - C. Statistical distributions
  - D. Collecting and summarizing data
  - E. Measurement system analysis (MSA)
  - F. Process and performance capability
- IV. Analyze Phase (15 Questions)

- A. Exploratory data analysis
- B. Hypothesis testing
- V. Improve Phase (15 Questions)
  - A. Design of experiments (DOE)
  - B. Root cause analysis
  - C. Lean Tools
- VI. Control Phase (11 Questions)
  - A. Statistical process control (SPC)
  - B. Control plan
  - C. Lean tools for process control

## **Pedagogical Goals**

The learning model developed by Kolb<sup>3</sup> is widely used in the academic community. The same model has been embraced for Six Sigma certification<sup>1</sup>. Although the levels of the model have been renamed, the underlying concepts are the same. At the lowest level there is some memory of a topic. As the learner moves to higher intellectual levels they eventually move through application to eventually develop new knowledge. The six sigma green belt criteria generally expect abilities in the middle of the hierarchy.

- Remember
- Understand
- Apply
- Analyze
- Evaluate
- Create

## **Grand Valley State University Manufacturing Curriculum**

The Product Design and Manufacturing Engineering program at Grand Valley State University is four years in length with an integrated cooperative education experience. The courses that directly address the Six Sigma criteria are required for all students. Each course is listed with course descriptions. The sequence of courses listed matches the order in the curriculum.

EGR 106 - Introduction to Engineering Design I - A first course in the principles and practice of multi-disciplinary engineering analysis, design, construction, and evaluation. Topics include graphical communication, solid modeling, computer-aided manufacturing, computer programming fundamentals, structured programming, and principles of digital and analog electronics. Professional skills such as teamwork, problem solving, and communication (oral and written) are emphasized.

EGR 107 - Introduction to Engineering Design II - A second course in the principles and practice of multi-disciplinary engineering analysis, design, construction, and evaluation. Topics include graphical communication, solid modeling, computer aided manufacturing, computer programming fundamentals, structured programming, and principles of digital and analog electronics. Professional skills such as teamwork, problem solving, and communication (oral and written) are emphasized.

STA 220 - Statistical Modeling for Engineers - This is a first course in statistics using modeling as the unifying framework upon which to build understanding of applied statistical analysis. Focus is on applications of statistical modeling with real and simulated data. Topics include descriptive statistics, probability, data management, statistical modeling and inference. Open only for engineering students.

EGR 220 - Engineering Measurement and Data Analysis - Measurement and data analysis lab that complements STA 220. This course uses hands-on engineering tests and experiments to build understanding of applied statistical analysis. The use of various measurement and data acquisition tools and data analysis techniques are introduced. Technical writing in the form of lab reports is introduced and emphasized. Offered fall and winter semesters.

EGR 289 - Engineering Co-op Preparation - Introduces potential engineering cooperative education students to the industrial environment, the manufacture of quality products, and the basic principles of leadership. Helps students develop a better self-understanding through self-assessment and career development theory and prepares students for the co-op interview process.

EGR 250 - Materials Science and Engineering - The internal structure, composition, and processing of metals, polymers, and ceramics are related to their properties, end use, performance and application in engineering. Materials selection exercises are included. Laboratory. (3-0-3) Offered winter and spring/summer semesters.

EGR 309 - Machine Design I - Topics include shear and bending stresses in beams, beam deflections, statically indeterminate beams, planar combined loading, triaxial stress and strain transformations, static failure theories, fatigue failure theories, surface failures, belt and chain drives, clutches and brakes, finite element analysis for planar loading, introduction to strain gauges and rosettes.

EGR 290 - Engineering Co-op 1 - The first full-time four-month cooperative engineering work experience usually in a local industrial/manufacturing firm. Reading, writing assignments required.

EGR 301 - Analytical Tools for Product Design - Analytic methods in product design are integrated into a coherent design process that includes: gathering customer requirements, establishing specifications,

generating alternative concepts, estimating feasibility, concept selection, embodiment design, design refinement, prototyping and project planning.

EGR 345 - Dynamic System Modeling and Control - An introduction to mathematical modeling of mechanical, thermal, fluid, and electrical systems. Topics include equation formulation, Laplace transform methods, transfer functions, system response and stability, Fourier methods, frequency response, feedback control, control actions, block diagrams, state variable formulation, computer simulation. Emphasis on mechanical systems.

EGR 367 - Manufacturing Processes - The fundamentals of manufacturing processes and the machinery of production. The forming of metals, plastics, ceramics and composites with an emphasis on the economics of engineering designs and designs that can be practically manufactured. Computer aided manufacturing and quality control processes. Metrology.

EGR 390 - Engineering Co-op 2 - The second full-time four-month cooperative engineering work experience usually in a local industrial/manufacturing firm. Reading, writing assignments required.

EGR 401 - Advanced Product Design - Advanced topics in product design are integrated to prepare students to develop a prototype into a manufacturable design. The course will cover topics such as analysis of competitive product, protection of intellectual property, product architecture, material and process selection, experimental design, advanced tolerance analysis, rapid prototyping and risk amelioration. Course material will be reinforced with design project work.

EGR 440 - Production Models - An introduction to analytic and simulation models as well as their application to current production strategies, particularly lean manufacturing. Emphasis on workstations, inventories, flow lines, Kanban and CONWIP, and cellular manufacturing. Computer based solution techniques, case studies, and case problems are employed.

EGR 450 - Manufacturing Control Systems - An introduction to the control of machines and processes widely used in manufacturing. Topics include programmable logic controllers, actuators and sensors for discrete and continuous systems, structured design techniques, memory structures, data handling functions, A/D and D/A converters, data communications, and hierarchical control. The technical issues involved in implementing control schemes are discussed.

EGR 490 - Engineering Co-op 3 - The third full time, four month cooperative engineering work experience usually in a local industrial/manufacturing firm. Reading, writing assignments required.

EGR 485 - Senior Engineering Project I (Capstone) - An independent investigation of theoretical or experimental design problems in engineering. The nature and scope of the project are determined by the student in consultation with the instructor and depend upon the facilities available. Normally this project is carried out during the entire senior year, with one-hour of credit during the first semester and two hours of credit during the second semester. A written technical report is required. All seniors meet together each week to discuss their projects with each other and their supervisor.

EGR 486 - Senior Engineering Project II (Capstone) - Continuation of student's work in EGR 485. Both an oral report and a final written technical report are required.

Other foundation, technical, elective, and liberal arts courses are omitted for brevity or because they are options that may not be taken. Note that a student with particular interest in quality may take additional courses. Technical core and elective courses that are not considered include:

BIO 105 - Environmental Science  
CHM 115 - Principles of Chemistry I  
ECO 210 - Introductory Macroeconomics OR ECO 211 - Introductory Microeconomics  
EGR 209 - Mechanics and Machines  
EGR 214 - Circuit Analysis I  
EGR 226 - Introduction to Digital Systems  
EGR 309 - Machine Design I  
EGR 360 - Thermodynamics  
EGR 403 - Medical Device Design  
EGR 405 - Materials Failure Analysis and Selection  
EGR 409 - Machine Design II  
EGR 445 - Robotics Systems Engineering  
EGR 447 - Engineering Mechanics of Human Motion  
EGR 453 - Biomedical Materials  
EGR 463 - Alternative Energy Systems and Applications  
MTH 201 - Calculus I  
MTH 202 - Calculus II  
MTH 203 - Calculus III  
MTH 302 - Linear Algebra and Differential Equations  
PHI 102 - Ethics  
PHY 230 - Principles of Physics I  
PHY 234 - Engineering Physics  
STA 315 - Design of Experiments  
WRT 150 - Strategies in Writing

Another important note is the nature of the cooperative education system. Each student is placed with an employer that provides exposure to their processes, systems, and expectations. The result is that many, but not all, students have had training and use of systems like FMEA, process studies, etc. In addition, if they are working with an employer that has a strong Six Sigma program, they will receive formal training in many of the core topics. It is a testament to a joint

education experience that benefits students. Of course the other outcome is that the experiential knowledge is not consistent in depth and coverage.

### Relating the Curriculum to Green Belt Criteria

The general categories of the CSSGB requirements are listed in Table 1. The columns are the learning levels defined by the ASQ. Each of the Grand Valley State University courses are added where they address requirements and how much so by column placement. For example, in EGR 107 the students are introduced to the concepts of project management including work breakdown, Gantt charts, and budgets. The CSSGB standards are also indicated with ‘STD’ highlighted in blue. In some cases the categories range for ability, in those cases the highest expected level is indicated.

Table 1 - Courses and CSSGB Standards Mapped by Learning Level

SSGB Criteria	Remember	Understand	Apply	Analyze	Evaluate	Create
I.A. Six sigma and organizational goals		STD				
I.B. Lean principles in the organization			STD EGR 440			
I.C. Design for six sigma (DFSS) methodologies				STD		
II.A. Project identification			EGR 401	STD EGR 485 EGR 486		
II.B. Voice of the customer (VOC)	EGR 106, EGR 107		STD EGR301	EGR401, EGR 485		
II.C. Project management basics	EGR 106 EGR 290	EGR 107	STD	EGR 301 EGR 485		
II.D. Management and planning tools			STD EGR 485 EGR 486 EGR 301 EGR 401			
II.E. Business results for projects			EGR 390 EGR 490 EGR 367	STD EGR 485 EGR 486 EGR 490		
II.F. Team dynamics and performance	EGR 106, EGR 107	EGR 301	STD EGR 485, EGR 486			



III.A. Process analysis and documentation	EGR 290	EGR 390	ERG 367 EGR 485 EGR 490			<b>STD</b>
III.B. Probability and statistics			<b>STD</b>	EGR 220 STA 220		
III.C. Statistical distributions		<b>STD</b>	EGR 220 STA 220	EGR 301 EGR 367		
III.D. Collecting and summarizing data	EGR 106, EGR 107		EGR 345	EGR 220 STA 220 EGR 367	<b>STD</b> EGR 485 EGR 486 EGR 440	
III.E. Measurement system analysis (MSA)	EGR 220		EGR 367		<b>STD</b>	
III.F. Process and performance capability		EGR 220	EGR 367 EGR 440		<b>STD</b>	
IV.A. Exploratory data analysis	EGR 106	EGR 107		EGR 220 EGR 301 EGR 401 STA 220	EGR 485 EGR 401	<b>STD</b>
IV.B. Hypothesis testing	EGR 106	EGR 107		<b>STD</b> EGR 220 STA 220		
V.A. Design of experiments, DOE			<b>STD</b>	EGR 367 EGR 401		
V.B. Root cause analysis			EGR 301 EGR 485	<b>STD</b> EGR486 EGR 401		
V.C. Lean Tools			EGR 440	<b>STD</b>		
VI.A. Statistical process control (SPC)			EGR220, STA220	<b>STD</b> EGR 367		
VI.B. Control plan			<b>STD</b>			
VI.C. Lean tools for process control		<b>STD</b>				

From a distance the chart shows a reasonable match between undergraduate curriculum and the CSSGB. Notable lags occur in a few of the topics focused on Six Sigma management and programs. Additionally there are lags for some of the organizational tools for processes. However, the undergraduate curriculum leads for many topics on a theoretical nature.

Without any other coursework and/or cooperative education experience an undergraduate student would be poorly prepared to pursue the CSSGB recognition. However, it would be possible to address these gaps with an elective course <sup>5</sup>. The topics in such a course are listed. The one barrier would be the selection of a process family to apply the topics. One example where this worked well was a plastics engineering technology minor <sup>6</sup>. A lower impact alternative is for an instructor to adopt various topics for use in the classroom, laboratory, or project <sup>4</sup> work.

1. Value of six sigma
2. Organizational goals and six sigma projects
3. Organizational drivers and metrics
4. Road maps for DFSS
5. Basic failure mode and effects analysis (FMEA)
6. Design FMEA and process FMEA
7. Process analysis and documentation
8. Measurement system analysis (MSA)
9. Process and performance capability
10. Process performance vs. process specifications
11. Process capability studies
12. Short-term vs. long-term capability and sigma shift
13. Exploratory data analysis
14. Multi-vari studies
15. Correlation and linear regression
16. Control plan
17. Total productive maintenance (TPM)
18. Visual factory

Many of the leads and lags are for topics that are industry and process specific. It is reasonable to argue that these should be left to the employers and new employees. In that case the list of topics can be used as a guideline for career development.

## **Conclusion**

A manufacturing engineering curriculum has been mapped to the six sigma green belt certification body of knowledge. The mapping was done for the minimum level of coursework, ignoring additional topics that may have been studied in elective courses, or during their cooperative education semesters. A table was developed to map academic to certification topics. It reveals that a good portion of a manufacturing curriculum satisfies the six sigma criteria. And, that the gaps are in areas that are better suited to postgraduate professional experience. Currently the CSSGB examination is not offered to students in the program. However this map is the first important step in that direction.

As mentioned before, the authors are not suggesting that curriculum should be explicitly designed to satisfy the six sigma certification criteria. However the CSSGB body of knowledge can inform the process of curriculum review and revision and may aid in establishing a baseline set of skills and knowledge expected by industry. In addition it can enrich academic-industry discussions. Industry can also benefit from the list of topical gaps as they hire and train new employees.

Faculty are encouraged to repurpose the table created for the Grand Valley State University curriculum for their own purposes. It will be particularly valuable when working with industry and when demonstrating industry relevance for accreditation. And, programs that cover most or all of the six sigma certification topics can consider offering the certification exam to their students.

## References

1. American Society for Quality (ASQ) Certified Six Sigma Green Belt (CSSGB) Body of Knowledge, 2014.
2. Tennant, G., SIX SIGMA: SPC and TQM in Manufacturing and Services. Gower Publishing, Ltd., 2001.
3. Kolb, D.A., Experiential learning: experience as the source of learning and development, Englewood Cliffs, New Jersey: Prentice-Hall, 1984.
4. Zhan, W., Porter, J., “Teaching Six Sigma in a Course Project”, ASEE Annual Conference, June 2008.
5. Uddin, M., Chowdhury, A.R., “Integration of ‘Six Sigma’ Into the Undergraduate Engineering Curriculum”, ASEE Annual Conference, June 2004.
6. Leduc, A., “Six Sigma: Does it Belong in the Manufacturing Curriculum”, ASEE Annual Conference, June 2008.