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Six Sigma Black Belts: What Do They Need to Know?

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The Six Sigma improvement methodology has received considerable attention recently, not only in the statistical and quality literature, but also within general business literature. In published discussions, terms such as "Black Belt"(BB), "Master Black Belt," and "Green Belt" have frequently been used indiscriminately, without any operational definitions provided. It may not be clear to readers exactly what a "Black Belt" is, what training he/she should have, and what skills he/she should possess. Those hiring "Black Belts" may also be confused. The discussants and I have a significant opportunity to clarify how statisticians, quality professionals, and business leaders think about Six Sigma, and quality improvement in general. The specific purpose of this article is to provide a context and forum for discussion of the technical skills required by Six Sigma BBs, with the hope of reaching a general consensus. I focus on BBs since they are typically the backbone of Six Sigma initiatives. Some previously published examples of BB curricula will be referenced, while additional input will come from my experience in various areas of GE, as well as recent general trends in applied statistics. I then present a recommended BB curriculum, and compare it to the Certified Quality Engineer (CQE) criteria. Other relevant issues in developing BBs are also discussed.

Introduction

The Six Sigma improvement initiative has become extremely popular in the last several years. In addition to generating a great deal of discussion within statistical and quality circles, it has been one of the few technically oriented initiatives to generate significant interest from business leaders, the financial community, and the popular media. For example, a recent book on Six Sigma (Harry and Schroeder (2000)) made the New York Times best seller list.

I assume that the reader is already familiar with the basic concepts of Six Sigma. Numerous books and articles are available to provide a background on Six Sigma, such as Harry and Schroeder (2000), Hoerl (1998), Hahn et al. (2000), and Agrawal and Hoerl (1999). The focus of this article will therefore be on the specific skill set that Six Sigma Black Belts need and how to go about developing that skill set. The reason for this focus is that numerous authors on Six Sigma use terms such as "Black Belt," "Master Black Belt," and so on with little or no operational definition of what these people actually do or what skills they have. Based on various conversations I have had at professional conferences, this confusion has been a stumbling block to organizations attempting to implement the Six Sigma methodology.

More recently there has been discussion and debate about how the skills of Black Belts or Master Black Belts compare to those of a Certified Quality Engineer (CQE). See Munro (2000) for an example. Because of the large number of individuals who have earned one or both of these different titles, and because of the large number of consultants doing training in the field, it is important to understand

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TABLE 1. List of Acronyms

ANOVA – Analysis of variance
ASQ – American Society for Quality
BB – Black Belt
CEO – Chief Executive Officer
CQE – Certified Quality Engineer
CTQ – Critical to quality metrics
DFSS – Design for Six Sigma (Six Sigma applied to design)
DMAIC – the Define, Measure, Analyze, Improve, Control sequence
DOE – Design of experiments
FMEA – Failure modes and effects analysis
GB – Green Belt
GE – General Electric Corporation
ID – Interrelationship digraph (knowledge based tool)
MBB – Master Black Belt
MS – Master of Science Degree
QFD – Quality function deployment
RSM – Response surface methodology
R&R – Repeatability and Reproducibility
SIPOC – Process map identifying suppliers, inputs, process steps, outputs, and customers
SPC – Statistical process control

the differences where they exist. Therefore, I discuss the work that a Six Sigma Black Belt (BB) actually does, and then what specific skills are required to do this work. This will be documented in the form of a recommended curriculum. I focus on BBs because I view them to be the technical backbone of successful Six Sigma initiatives—the folks who actually generate the savings.

I begin by briefly reviewing the types of projects a BB might lead, which will help me explain their role. Once I have clarified their role and actual work, it will be easier to discuss appropriate technical skills, and therefore training, required to do this work. I then compare BB curricula with the CQE requirements as well as a typical MS in applied statistics curriculum. Lastly, I discuss other BB development issues that are relevant, such as selection of candidates, mentoring after the training, and impact on career paths.

Because of the large number of acronyms, I list all acronyms used in this paper in Table 1.

What is the Role of a BB?

In this section, I begin by describing some examples of projects that Black Belts have been leading in GE before discussing the BB role itself. The examples discussed here come from a variety of different business contexts, but they all demonstrate how analytical Six Sigma methods have been used to help understand and address business issues. It should be noted that none of these are traditional manufacturing examples because of the types of organizations with which I have been primarily working—finance and other general business operations. Obviously, BBs perform corresponding improvement activities in manufacturing and engineering. Due to confidentiality issues, I am not at liberty to reveal details of the actual tools applied, or specific financial results obtained. Rather than trying to “sell” Six Sigma to the reader, my intent is only to give an overview of the types of projects for which a BB may be responsible. I trust that there is enough detail provided to accomplish this objective.

Examples of BB projects

Website Download Time

In this example, a business was providing information to customers over a website. This website had many customers, but was attempting to gain greater market share from its competitors. Market research had indicated that a primary concern for customers was the length of time that individual website pages take to download.

To understand how to improve download time for this website, a designed experiment (DOE) was constructed. The goal of this DOE was to model how both the average and the variation of download time were affected by various factors including architecture of the page and various technological options available. The DOE was conducted to simulate both personal (home) and commercial (office) users of the website in order to best capture the full range of potential customer experiences.

The result of the DOE was the identification of those factors that have the most impact on the download speed of the website. The business used the results of the DOE to prioritize the order in which they worked on the improvements. At the time of this writing, most of the changes have been implemented, and the results have been found to closely follow the predictions from the model based on the DOE. Control mechanisms have also been put in place to allow senior management to track the download speed (and other key variables) over time. The financial benefits have been substantial.

Customer Retention

Another example of a Black Belt project involves understanding customer profiles at a health care insurance business. The business sold insurance to individuals nationally. At the initiation of this project, the business had seen the number of policy lapses increase. In other words, more people were not renewing their policies. The business wanted to understand the financial impact that this might have, and what might be done to reverse the trend.

The approach that the Black Belt used here was to determine which factors in a customer profile are predictors of policy lapses for the business. She was able to show that certain factors in a customer profile were strongly correlated to higher lapses. She then investigated the population of customers that were lapsing in their insurance policies, according to those factors. She was thus able to estimate the financial impact that the business would see as a result of these lapsed policies. The ultimate objective, of course, was to prevent lapses of profitable policies and encourage lapses of unprofitable ones. The financial benefits are just beginning to be recognized.

Equipment Delivery

One of the GE businesses promises to deliver equipment to their customers anywhere in the US, within a matter of days. They consider this to be one of their competitive advantages, in that their fulfillment process is superior to that of their competitors. They were interested in determining the factors that were driving the variation in equipment delivery cycle time.

The business had an enormous amount of data associated with their equipment delivery process, although when they evaluated the data quality via a "gauge R&R" (generic Six Sigma term for measurement system evaluation), they found some issues requiring improvement of their data collection and management process. They were able to collect "good" data on a large number of factors that were potentially influencing the fulfillment process including the type of equipment that was being delivered, the plant that was manufacturing the equipment, the geographic location of the customer, and various other factors. The business was able to determine which of these factors was having the largest effect on the variation associated with equipment delivery cycle time and focus improvement efforts on those. Improvement efforts to reduce the delivery cycle time variation are ongoing. In this case, there will be some cost savings due to reduced rework in the delivery process, but the primary benefit will be top line growth from improved customer satisfaction.

The BBs Fit Within the Organization

While the focus of this article is on skills required by BBs, it is important to understand how BBs fit into the bigger picture in order to understand their role. The overall effort within an organization is typically led by a Quality Leader, or perhaps "Champion." The Quality Leader's work is primarily strategic—developing an implementation strategy, setting objectives, allocating resources, monitoring progress, and so forth. The Master Black Belts (MBBs) have a more "managerial" role, in that they often are responsible for all Six Sigma work done in a particular area or function. Typical duties include selection, training, and mentoring of BBs, project selection or approval, and review of projects completed. MBBs are expected to have a deeper technical knowledge of the tools as well as other "soft" skills.

The BB is in a more operational role, that of rolling up the sleeves and making improvements happen. Within GE, the MBBs and BBs have been full-time resources, freed up from their "regular jobs" to focus on Six Sigma. (In GE, people who are trained and doing Six Sigma projects as part of their "regular job" are referred to as Green Belts (GBs).) In GE, BBs have also generally reported to the Six Sigma

Quality Leader, rather than to the leader of the business function in which they are working. An important point, which I return to later, is that the BB role is intended to be a temporary assignment—typically two years. The BB role is viewed as an important developmental experience, which the BBs will benefit from during the remainder of their careers. This has huge implications for BB selection that is discussed below.

In most cases, a BB is a leader of a team that is working on a problem. Therefore, while possessing the ability to apply statistical tools to solve real problems is paramount to performing the role, other skills are needed as well. These include organizational effectiveness skills, such as team and project leadership, as well as skills in meeting management. One reason these "management" skills are important is that the typical BB leads several projects at the same time, i.e., they are "multi-tasking." I agree with a reviewer who points out that in today's business environment, everyone is basically multi-tasking and managing several projects, each of which needs to produce hard financial results.

Other "soft skills" required for the BB to be effective include the ability to clearly present the results of projects, both orally and in writing. In addition, training skills are very helpful since the BB may have to do some degree of training if team members have not yet been Six Sigma trained. (Hopefully, the entire team is Green Belt trained, but even so this is not as in-depth as the BB training.) The mentoring which the BB receives from the MBB may involve instruction in some of these skills in addition to technical mentoring. In summary, BBs must be results-oriented leaders who also possess the right technical skills. Their training should focus on the skills they need to perform this role effectively. Conversely, it should not be based on "typical" statistics curricula in academia or business.

After completing a certain number of financially successful projects, BBs are "certified." The exact number of projects varies by business, but would typically be in the range of 5-15. External training organizations, such as ASQ and the University of Tennessee Center for Executive Education, may certify after a single project. The specific rewards for BB certification also vary by business, but may include both financial (e.g., raise, bonus, stock options) and non-financial (e.g., meeting business CEO, peer recognition) rewards. One issue to be noted is that there are no standardized criteria for certification, as there are with accountants, lawyers, and engineers, hence being a "Certified BB" has little meaning without knowing the specific certification criteria.

Developing the Technical Skills

In this section, I will discuss the curriculum which is needed to develop the technical skills required to achieve significant improvements in BB projects. Recall that other skills are also needed, as discussed above. I begin by reviewing a published BB curriculum, then present a curriculum I have used, and finally report a proposed curriculum. This is then compared to the CQE criteria and that for an MS in applied statistics. I then briefly discuss the proper structuring of the training.

Sample Curriculum

Hahn et al. (1999) present a sample curriculum that is reproduced in Table 2. This curriculum is not necessarily exactly what is presented by Honeywell/Allied Signal, GE, or Sigma Breakthrough Technologies, the three companies represented by the authors, but is fairly representative of BB training in general. ASQ's curriculum, posted on their website, and summarized in the discussion of this paper, appears similar. By definition, the ability to apply these tools in an integrated manner is considered the core of the technical skills required by BBs. The weeks correspond roughly to the Measure, Analyze, Improve, and Control (MAIC) phases. (GE and others have added a "Define" phase at the beginning, to assure that the right projects are selected.) Note that this is approximately 160 contact hours, fairly focused, and is spread out over about four months. In other words, the four weeks are not back-to-back, but spaced about a month apart. For reference, consider that a typical one-semester course in a university has about 40 contact hours.

A point I will return to shortly is the fact that there is formal training in the use of the DMAIC roadmap. This teaches the BBs how to integrate the various tools into an overall approach to process improvement. They are taught how to get an improvement project going, how to transition from phase to phase, and how to close out the project. Each tool is then taught within the context of this roadmap, so it is immediately obvious why, when, and where each tool should be used. In addition, some technical, but non-statistical, topics are included, such as quality function deployment (QFD) and failure modes and effects analysis (FMEA). Thus, Six Sigma tends

TABLE 2. Sample Black Belt Curriculum From Hahn et. al. (1999)

Week 1

- Six Sigma Overview & the MAIC Roadmap
- Process Mapping
- QFD (Quality Function Deployment)
- FMEA (Failure Mode and Effects Analysis)
- Organizational Effectiveness Concepts
- Basic Statistics Using Minitab
- Process Capability
- Measurement Systems Analysis

Week 2

- Review of Key Week 1 Topics
- Statistical Thinking
- Hypothesis Testing and Confidence Intervals (F, t, etc.)
- Correlation
- Multi-vari Analysis and Regression
- Team Assessment

Week 3

- ANOVA
- DOE (Design of Experiments)
  - Factorial Experiments
  - Fractional Factorials
  - Balanced Block Designs
  - Response Surface Designs
- Multiple Regression
- Facilitation Tools

Week 4

- Control Plans
- Mistake-Proofing
- Team Development
- Parallel Special Discrete, Continuous Process, Administration, and Design Tracks
- Final Exercise

to combine traditional statistical tools with tools from other disciplines, such as engineering design (FMEA), organizational effectiveness, problem solving (mistake proofing, multi-vari analysis), or quality improvement (QFD). An actual business project is worked on through the training, so that the BB-in-training can immediately apply the appropriate tools learned to a real project.

There is variation within Six Sigma curricula, of course, as within any other field. While much of the core technical material, such as experimental design and statistical process control, are common across virtually every provider, the breadth and depth of coverage of topics will vary. For example, GE has significantly reduced the treatment of basic probability and added more emphasis on graphical techniques (scatter plots, box plots, and so on) compared to the training originally presented to GE by the Six Sigma Academy. The University of Tennessee Center for Executive Education awards a BB certificate for completing their three week Practical Strategies for Process Improvement course, followed by their one week DOE course, and also successfully completing a BB project on the job (with mentoring from the instructors). This is perhaps the most non-standard approach of which I am aware. The University of Texas currently advertises an "accelerated" two-week BB course, using instructors from Air Academy. While it is certainly possible to streamline and potentially shorten any training sequence, it is also true that developing the appropriate breadth and depth of

TABLE 3. GE Finance-Oriented Curriculum

Week 1

- The DMAIC and DFSS (Design for Six Sigma) improvement strategies
- Project selection and scoping (Define)
- QFD
- Sampling principles (quality and quantity)
- Measurement system analysis (also called "Gauge R&R")
- Process capability
- Basic graphs
- Hypothesis testing
- Regression

Week 2

- DOE (focus on 2-level factorials)
- Design for Six Sigma tools
- Requirements flowdown
- Capability flowup (prediction)
- Piloting
- Simulation
- FMEA
- Developing control plans
- Control charts

Week 3

- Power (impact of sample size)
- Impact of process instability on capability analysis
- Confidence Intervals (vs. hypothesis tests)
- Implications of the Central Limit Theorem
- Transformations
- How to detect "Lying With Statistics"
- General Linear Models
- Fractional Factorial DOEs

knowledge takes time, and two weeks seems like a severe shortening of training.

Finance-Oriented Curriculum

GE has used a curriculum in GE financial organizations that differs somewhat from that referred to in Table 2. The main reason for the differences is that this course is specifically tailored to people with financial backgrounds who will be primarily applying Six Sigma in financial, general business, and e-commerce processes. For example, we have found DOE to be very applicable in finance (pricing studies, collections, etc.), but we have not had response surface methodology (RSM) applications in finance, and hence RSM is not in our curriculum. In addition, a third week was added to an existing Green Belt curriculum in order to upgrade to a BB curriculum. This is why some topics, such as DOE, are split between weeks. This training contains three "weeks," and primarily covers the technical subjects listed in Table 3.

In teaching these tools, we try to follow a few basic principles:

- As always, real examples are critically important to both motivation and learning. Presenting real "front to back" case studies which illustrate the overall flow of the DMAIC process, i.e., how the individual tools are integrated into an overall approach to process improvement, is key. Unfortunately, most of these case studies are considered proprietary by management and cannot be published. However, other sources of sequential case studies are Hoerl and Snee (2002) and Peck, Haugh, and Goodman (1998).

We have also found that it is very important to use contexts as close to what the students are experiencing as possible. Because we are dealing with organizations that are not in a manufacturing environment, we do not use any manufacturing examples when discussing the tools above. All the examples, illustrations, exercises, and cases studies that we give in class are as close as possible to the types of contexts that they will deal with, i.e., accounts payable, collections, realization of revenue, inventory valuation, e-commerce, and so on.

- One must provide examples of how each tool has been used. We supplement the technical training of this material with as many real financial examples as possible to illustrate where these tools have actually been used by colleagues in finance. This has been extremely successful in avoiding the whole "we're different, this doesn't apply to us" debate. The students have given feedback many times that the use of these examples is absolutely critical to enable them to link what they are learning in class to their day to day activities. We have been fortunate in that the longer the experience we have with such organizations, the more diverse the examples we've been able to use to demonstrate how the use of these tools has added value to the work they do.
- We do not teach Minitab (see www.minitab.com) or other statistical software used as separate topics. Rather, we teach the use of the software application as we are teaching the tool. When possible, we have the students use the software themselves in class. So, for example, we use the famous helicopter example (Box and Liu (1999)) in DOE, and have students breakout into groups and perform the experiment in class. Setting up the experiment and analyzing the data in Minitab is part of the exercise.
- We only teach "theory" in so far as it is needed by students in their improvement projects. For example, we teach no theory behind t-tests, ANOVA, F-tests, etc. We simply teach why and when one would want to use these methods, how to "push the buttons" in Minitab, and most importantly, how to properly interpret the computer output. By focusing on p-values, we are able to avoid going through the formulas for each test. While use of p-values is controversial in academic circles, we have found use of p-values useful in getting financial people to effectively use hypothesis tests. Of course, we explain in Week 3 why p-values can be misleading based on sample size, special causes in the data, or poor choice of metric. We also teach confidence intervals as a desirable alternative to formal hypothesis testing in most cases.
- The overall structure to the course, as well as to each topic, is involved in answering the following questions:
  - — Why would I use this? We typically address this question by beginning with a discussion of real problems they face on a regular basis, or referring back to the overall DMAIC or DFSS models.
  - — What does this do? This is explained by showing real case studies where the tool has actually been applied to the type of work the student does. This develops gross conceptual understanding and the motivation that this tool can help the student become a better financial analyst.
  - — How do I do it? Only at this point do we go into detail about how to use a specific tool.

I should also mention here that immediately following the training, we test students on their comprehension of the material. Failure to pass the exam requires them to rewrite the test at a later date or retake the training. Concerning teaching methods, a reviewer of a previous version of this paper commented: "perhaps the method of teaching to embed the tools within a framework and to provide instant application is more important than the tools themselves. Is there evidence beyond your GE experience to validate this hypothesis?" I agree with this insightful comment, and refer the interested reader to Hoerl and Snee (1995) and also Snee (2000) for more evidence of its validity.

Relevance to Other Curricula

The finance-oriented curriculum described above was developed specifically for BBs that would be doing applications in the finance area. I feel, however, that it serves as a good base and can be amended according to the targeted group of interest. Clearly, the examples associated with the training should be drawn from contexts of interest to the audience, as I discussed above. I have found that nothing helps the students understand how the training material applies to their job as much as seeing examples of where they have been applied in similar contexts and impacted business. A general recommendation would be to tailor both the course emphasis and examples to the functional area of the students. Tailoring the course emphasis requires analysis of the students' work to understand which tools and approaches are likely to be most useful to them. I am not in favor of "one size fits all" training, even though it is much easier to administer.

If the target audience is working in a manufacturing environment, then it may be appropriate to spend more time than suggested above on DOE. It may also make sense to expand the areas of discussion. For example, I have found when dealing with engineers working with chemical processes that mixture experiments are relevant. Similarly, when working with people in the design functions for products, response surface methodologies may be appropriate. In addition, if I were designing a BB curriculum from "scratch" I would likely integrate the Week 3 training topics within the general DMAIC (Define, Measure, Analyze, Improve, Control) and DFSS (Design for Six Sigma) flow of Weeks 1 and 2.

A Recommended Curriculum

Considering what we have seen in general BB curricula (Table 2), as well as GE's experiences within financial organizations, I would like to recommend a curriculum. This 4-week recommended curriculum is shown in Table 4. While it is intended for a manufacturing environment, it could be easily modified for other audiences through changes in emphasis and length and by replacing the examples and exercises with those from the appropriate application area.

Since this curriculum is similar in many respects to the curricula in Tables 2 and 3, I will focus the discussion here on a few key aspects of this curriculum. I believe it is important to begin training by explaining the context of Six Sigma, i.e., *why* we are doing it, and what we hope to accomplish with it. Next, it is important to illustrate the "whole" of Six Sigma through "front to back" sequential case studies which illustrate how the individual tools are integrated into overall approaches to improvement. Students do not need to understand the details of each tool to grasp the big picture, i.e., *what* a Six Sigma project is. This is important because my experience has indicated that students struggle more with the proper "flow" from phase to phase than they do with the application of individual tools. Instructors should resist the temptation to jump into details of individual tools until the big picture is clear to the students. My experience is that this approach creates "suction" on the students' part, in that once they grasp the big picture, they are anxious to learn the details. I recommend using both complete Define-Measure-Analyze- Improve-Control (DMAIC) and complete Design for Six Sigma (DFSS) case studies to do this.

The presentation of the Define phase should emphasize selection of appropriate projects, development of project plans, and identification of the relevant process. Process thinking skills on the part of the students should not be assumed, especially outside of manufacturing. The SIPOC (supplier-input-process-output-customer) mapping exercise can be extremely helpful in obtaining a common understanding of the process, in identifying potential improvement areas, and generally in getting the project off to a good start. In the Measure phase, I feel that the issue of data quality (e.g., biased sampling, inaccurate data, etc.) is critically important and often overlooked. Students often assume that "a data point is a data point" until taught otherwise. This is needed in addition to understanding the impact of sample size (data quantity). Note that the issue of data quality goes well beyond measurement system analysis, in that we may be accurately and precisely measuring something from a very biased sample. The traditional Six Sigma measurement system analysis focuses on gauge R&R studies (repeatability and reproducibility). While these topics are important, they do not include more general measurement system issues such as accuracy, calibration, linearity, and stability over time. In addition, discrete data also have measurement issues, but do not lend themselves to gauge R&R analysis. I have not listed statistical thinking as a separate topic, as was done in Table 2, but rather imbed the key statistical thinking concepts of a process view of work, the importance of understanding and reducing variation, and the critical role of data in each topic. For example, I recommend teaching the *process* of performing a complete regression analysis, rather than focussing on the regression tools themselves.

Another unique aspect of this curriculum in the Measure phase is that it addresses the issue of process stability (statistical control) up front, rather than waiting for the Control phase where control charts are typically introduced. I feel that when originally collecting data, BBs should understand that it is unlikely that their processes will be stable. This will obviously impact the interpretation of any summary

TABLE 4. Recommended BB Curriculum (Manufacturing Orientation)

Context[1]
- Why Six Sigma
- DMAIC & DFSS processes (sequential case studies)
- Project management fundamentals
- Team effectiveness fundamentals

Define[1]
- Project selection
- Scoping projects
- Developing a project plan
- Multi-generational projects
- Process identification (SIPOC)

Measure[1]
- QFD
  - Identifying customer needs
  - Developing measurable critical-to-quality metrics (CTQ's)
- Sampling (data quantity and data quality)
- Measurement System Analysis (not just gauge R&R)
- SPC Part I
  - The concept of statistical control (process stability)
  - The implications of instability on capability measures
- Capability analysis

Analyze[2]
- Basic graphical improvement tools ("Magnificent 7")
- Management and planning tools (affinity, ID, etc.)
- Confidence intervals (emphasized)
- Hypothesis testing (de-emphasized)
- ANOVA (de-emphasized)
- Regression
- Developing conceptual designs in DFSS

Improve[3–4]
- DOE (focus on two level factorials, screening designs, and RSM)
- Piloting (of DMAIC improvements)
- FMEA
- Mistake-proofing
- DFSS design tools
  - CTQ flowdown
  - Capability flowup
  - Simulation

Control[4]
- Developing control plans
- SPC Part II
  - Using control charts
- Piloting new designs in DFSS

(The week in which the material appears is noted as a superscript) statistics or capability measures calculated. I do not feel that a complete treatment of control charts is required here, just an introduction to the concept of process stability and implications of instability using run charts. Of course, we would likely plant a "forward pointer" to the discussion of control charts in the Control phase. Note also that the typical "basic statistics" would be imbedded into the topic where it is needed, rather than taught as a separate topic. For example, at some point we need to define and discuss what a standard deviation is. We typically do this when getting into the interpretation of gauge R&R ratios (which we do prior to calculation of sigma levels).

In Analyze, I recommend stressing graphical improvement tools (Pareto chart, histogram, run chart, scatter plot, etc.) as a predecessor to, if not replacement for, formal statistical analyses. In addition, I strongly recommend stressing confidence intervals over hypothesis tests when doing formal statistical analyses. While I acknowledge a role for hypothesis testing in the overall toolkit, I feel that it has been grossly over-emphasized in Six Sigma (and general statistics) curricula. For example, confidence intervals tend to highlight the impact of low sample size when failing to find statistically significant differences, in that that the confidence limits for a difference will be extremely wide; hypothesis tests tend to hide the impact of low sample size, leading to the inappropriate conclusion that there really is no difference or effect.

As an aside, the conceptual difference between "accepting" the null hypothesis versus "failing to reject" the null hypothesis is not easy to convey, and often seems like hair-splitting to non-statisticians. Confidence intervals make it clear that zero is only one of many plausible values for the "true" difference. I would also recommend including some of the "management and planning tools" (Brassard and Ritter (1994)), such as the Affinity Diagram or Interrelationship Digraph, which we have found to be helpful to BBs leading teams.

In both Analyze and Improve I recommend including DFSS tools, such as CTQ (critical to quality metrics) flowdown and capability flowup (prediction). CTQ flowdown and flowup involve development of equations (transfer functions) which relate the average and variation in the x's to average and variation in the y's. For flowdown, we start with the average and variation we want in the y's, and derive what would be needed in the x's. In flowup, we obtain data on (or predict) what our process will actually produce in the x's, and predict the final performance on the y's (see the discussion of transmission of error in Section 17.2 of Box, Hunter, and Hunter (1978)). The control plans in Control should extend well beyond control charts and include procedures for process set-up, monitoring, control, and troubleshooting. The plans need to be complete enough to ensure that we maintain the gains over time. I also recommend use of the key concepts used in the GE finance-oriented training, such as:

- Use of a "Why-What-How" sequence for the overall course and each individual topic
- Use of student projects
- Heavy use of relevant examples and case studies
- Lots of in-class team exercises (30%+ of class time)
- Integration of software within each topic, rather than teaching it separately.

Of course, this curriculum should be tailored by each organization based on what they actually expect their BBs to do.

Supplemental Materials

It should be obvious that a four or five week course will not make a novice into a professional statistician. There is no attempt to do this in Six Sigma initiatives. There are certainly situations, however, where students need more in-depth skills than those provided by standard Six Sigma training. GE has set up "Level II" and "Level III" training classes for such situations, with basic Six Sigma training providing the "Level I" training. Examples are specialized courses in mixture designs (Level II) in GE Plastics and courses in reliability (Level II) or multidimensional tolerancing (Level III) for engineering-oriented businesses like GE Aircraft Engines. General recommendations for supplemental materials are listed in Table 5.

Structure of the Training

GE is currently in the process of transition in the way that BB training is delivered, and I briefly describe that transition here. I feel that this reflects how training will be delivered in the future.

Until very recently, all of the training described above was given in a classroom format. Typically, we would have classes that had anywhere from 15 to 50 students, and each "week" of training would take place over a period of three to four 10-hour days.

TABLE 5. Recommended Supplemental Materials

Failure Modes and Effects Analysis – Automotive Industry Action Group (1995b)
General DOE – Box, Hunter, and Hunter (1978); Montgomery (2000)
General Statistics – Walpole, Myers, and Myers (1997)
Measurement Systems Analysis – Wheeler and Lyday (1990); Automotive Industry Action Group (1990)
Mixture Designs – Cornell (1990)
Quality Function Deployment (QFD) – Cohen (1995)
Regression – Draper and Smith (1998); Montgomery, Peck, and Vining (2001)
Reliability – Meeker and Escobar (1998)
Response Surface Methodology – Myers and Montgomery (1995)
Statistical Process Control – Wheeler and Chambers (1992); Automotive Industry Action Group (1995a); Montgomery (2001)
Statistical Thinking – Hoerl and Snee (2002)
Time Series – Box, Jenkins, and Reinsel (1994)

Often in the evenings we would give some time for consultation, either on the training material specifically, or to allow students to discuss the work in which they were involved. (These students are used to working 16-hour days!) The weeks are spaced at least a month apart, to give time for digestion of the material, and even more importantly, to allow time to actually apply the material to a real project.

We are currently in the process of transitioning some of our training to an e-learning environment. This means that instead of bringing people together in one location, we are delivering the training virtually. Our current model involves having some of the training being delivered "self-paced," which means that students learn the material themselves, on their own, via the web. Other parts of the training are being delivered by an instructor, but over the web, using various different kinds of "real time collaboration" technology. There are also exercises and group projects with the training, and some of this is done by "virtual group" activities. This means that the students are placed in groups that may have members dispersed in different geographic locations. The projects, such as the helicopter experiment, would be done by people in these virtual groups. Clearly, there are many challenges that need to be overcome when transitioning to this type of delivery mechanism for training, and we are in the process of discovering and addressing them.

The business case for doing the training in this way is compelling. The amount of travel costs that are saved, not to mention the amount of time saved by not doing that traveling, is substantial, especially for an organization like corporate finance, which is literally spread out across the globe. We foresee that more and more training done by various organizations will be delivered in this way.

BB Curricula Comparisons

I now compare the typical BB curriculum to two standard "benchmarks," the Certified Quality Engineer (CQE) program of ASQ, and a typical MS in statistics.

Comparison to the CQE Body of Knowledge

ASQ has been certifying quality engineers for some time, and is now certifying BBs. Several authors, in Munro (2000) and in numerous letters to the editor of *Quality Progress*, have compared the knowledge or skills of CQEs with Six Sigma BBs. Considering the large number of people certified in one program or the other (or both), not to mention the numerous consultants involved in these programs, there is the real possibility of a negative "competition" erupting between BBs and CQEs. I would therefore like to take an objective approach to comparing the typical BB curriculum to the CQE body of knowledge. The latest version of the CQE body of knowledge on ASQ's webpage (www.asq.org) at the time of the writing of this article is shown in Figure 1. A person must pass an exam on these topics, as well as meet other criteria, in order to become a CQE. Clearly there is significant overlap between the CQE body of knowledge and the BB curriculum, particularly in the area of statistical methods.

So how do these programs compare? First of all, it must be noted that the CQE body of knowledge is significantly broader than a BB curriculum. This

I. MANAGEMENT AND LEADERSHIP IN QUALITY ENGINEERING (19 Questions)

- A. Professional Conduct and ASQ Code of Ethics
- B. Management systems for improving quality (e.g., policy deployment, benchmarking, goal setting, planning and scheduling, project management, quality information systems)
- C. Leadership principles and techniques (e.g., leading quality initiatives, team development, team building, team organization)
- D. Facilitation principles and techniques, (e.g., roles and responsibilities, conflict resolution)
- E. Training (e.g., needs analysis, program development, material construction, determining effectiveness)
- F. Cost of quality (e.g., concepts, data collection, and reporting)
- G. Quality philosophies and approaches (e.g., Juran, Deming, Taguchi, Ishikawa)
  - 1. Benefits of quality
  - 2. History of quality
  - 3. Definitions of quality
- H. Customer relations, expectations, needs, and satisfaction (e.g., QFD, customer satisfaction surveys)
- I. Supplier relations and management methodologies (e.g., qualification, certification, evaluation, ratings, performance improvement)

II. QUALITY SYSTEMS DEVELOPMENT, IMPLEMENTATION, AND VERIFICATION (19 Questions)

- A. Elements of a quality system
- B. Documentation systems (e.g., configuration management, document control)
- C. Domestic and/or international standards and/or specifications
- D. Quality audits
  - 1. Types and purpose of quality (e.g., product, process, system, registration, certification, 1st party, 2nd party, 3rd party, management, compliance)
  - 2. Roles and responsibilities of individuals involved in the audit process (e.g., audit team, client, auditee)
  - 3. Quality Audit Planning, Preparation, and Execution
  - 4. Audit reporting and follow-up (e.g., need for corrective action and verification)

III. PLANNING, CONTROLLING, AND ASSURING PRODUCT AND PROCESS QUALITY (33 Questions)

- A. Preproduction or pre-service planning process
  - 1. Classification of quality characteristics
  - 2. Design inputs and design review
  - 3. Validation and qualification methods
  - 4. Interpretation of technical drawings and specifications
  - 5. Determining product and process control methods
- B. Material Control
  - 1. Material identification, status, and traceability
  - 2. Sample integrity (e.g., avoiding contamination or misidentification)
  - 3. Material segregation
  - 4. Material Review Board (MRB)
- C. Acceptance Sampling
  - 1. General concepts (e.g., lot-by-lot protection, average quality protection, producers and consumers risk, operating characteristics [OC] curves)
  - 2. Definitions (AQL, LTPD, AOQ, AOQL)
  - 3. Standards (ANSI/ASQC Z1.4, ANSI/ASQC Z1.9)
  - 4. Acceptance sampling plans (single, double, multiple, sequential, continuous)
- D. Measurement Systems
  - 1. Terms and definitions (e.g., precision, accuracy, metrology)
  - 2. Destructive and nondestructive measurement and test methods
  - 3. Selection of measurement tools, gages, and instruments
  - 4. Measurement system analysis (e.g., repeatability and reproducibility, measurement correlation, capability, bias, linearity)
  - 5. Metrology (traceability to standard, measurement error, calibration systems, control of standards and integrity)

IV. RELIABILITY AND RISK MANAGEMENT (11 Questions)

- A. Terms and definitions (e.g., MTTF, MTBF, MTTR, availability, failure rate)
- B. Reliability life characteristic concepts (e.g., bathtub model)
- C. Design of systems for reliability (redundancy, series, parallel)
- D. Reliability and maintainability
  - 1. Prediction
  - 2. Prevention
  - 3. Maintenance Scheduling
- E. Reliability failure analysis and reporting
- F. Reliability / Safety / Hazard Assessment Tools
  - 1. Failure mode and effects analysis (FMEA)
  - 2. Failure mode and effects criticality analysis (FMECA)
  - 3. Fault-tree analysis (FTA)

V. PROBLEM SOLVING AND QUALITY IMPROVEMENT (25 Questions)

- A. Approaches (e.g., Kaizen, CI, PDSA)
- B. Management and planning tools (affinity diagrams, tree diagrams, process decision program charts, matrix diagrams, interrelationship digraphs, prioritization matrices, and activity network diagrams)
- C. Quality tools (Pareto charts, cause and effect diagrams, flowcharts, control charts, check sheets, scatter diagrams, and histograms)
- D. Corrective action (problem identification, correction, recurrence control, effectiveness assessment)

FIGURE 1. CQE Body of Knowledge.

fact is readily obvious by comparing Tables 2-4 with Figure 1. There is no attempt to teach a BB various quality theories, use of quality standards such as ISO-9000 or the Baldrige criteria, quality auditing, and so on. The BB curriculum is clearly focused on developing the ability to achieve tangible results in Six Sigma improvement projects.

BBs are specifically selected, trained, and evaluated on the basis of their ability to achieve results. As noted in Munro (2000), ability to achieve results is not a criterion for CQE certification. This point is not "hair-splitting;" any professional statistician knows a lot more about the tools than a typical BB, but not all professional statisticians would

E. Preventive action (e.g., error proofing, opportunities for improvement, robust design)
F. Overcoming barriers to quality improvement

VI. QUANTITATIVE METHODS (53 Questions)

A. Concepts of Probability and Statistics

1. Terms (e.g., population, parameter, statistic, random sample, expected value)
2. Drawing valid statistical conclusions (e.g., enumerative and analytical studies, assumptions and robustness)
3. Central limit theorem and sampling distribution of the mean
4. Basic probability concepts (e.g., independence, mutually exclusive, multiplication rules, complementary probability, joint occurrence of events)

B. Collecting and Summarizing Data

1. Types of data (continuous vs. discrete; variables vs. attributes)
2. Measurement scales (nominal, ordinal, interval, ratio)
3. Methods for collecting data (e.g., check sheets, coding data, automatic gaging)
4. Techniques for assuring data accuracy and integrity
5. Descriptive statistics (measures of central tendency, measures of variation, frequency distribution, cumulative frequency distribution)
6. Graphical Methods
   a. Depicting relationships (e.g., stem-and-leaf plots, box-and-whisker plots, run charts, scatter diagrams)
   b. Depicting distributions (e.g., histogram, normal probability plot, Weibull plot)

C. Properties and Applications of Probability Distributions

1. Discrete distributions (binomial, Poisson, hypergeometric, multinomial)
2. Continuous distributions (uniform, normal, bivariate normal, exponential, log normal, Weibull, Chi-square, Studentís t, F-distribution)

D. Statistical Decision-Making

1. Point and interval estimation (efficiency and bias of estimators, standard error, tolerance intervals, confidence intervals)
2. Hypothesis testing
   a. Tests for means, variances, and proportions
   b. Significance level, power, type I and type II errors
   c. Statistical versus practical significance
3. Paired comparison
4. Goodness-of-fit tests
5. Analysis of Variance (ANOVA)
6. Contingency tables

E. Measuring and Modeling Relationships Between Variables

1. Simple and multiple least-squares linear regression (e.g., calculate and use the regression model for estimation and inference, interpret regression statistics)
2. Simple linear correlation (e.g., calculate and interpret the correlation coefficient, perform hypothesis, test and calculate confidence interval for the correlation coefficient)

F. Designing Experiments

1. Terminology (e.g., independent and dependent variables, factors and levels, response, treatment, error, replication)
2. Planning and organizing experiments (e.g., objective, choice of factors and responses, defining measurement methods, choice of design)
3. Design principles (power and sample size, balance, replication, order, efficiency, randomization and blocking, interaction, confounding)
4. Design and analysis of one-factor experiments (e.g., completely randomized, randomized block)
5. Design and analysis of full factorial experiments
6. Design and analysis of two-level fractional factorial experiments
7. Taguchi robustness concepts

G. Statistical Process Control (SPC)

1. Objectives and benefits
2. Selection of variable
3. Rational subgrouping
4. Selection and application of control charts (x-bar & r, x-bar & s, individual and moving range [ImR], moving average and moving range [MamR], median, p, np, c, u)
5. Analysis of control charts (common vs. special causes of variation and rules for determining statistical control)
6. Pre-control
7. Short-run SPC

H. Analyzing Process Capability

1. Designing and conducting process capability studies
2. Calculating process performance vs. specification
3. Process capability indices (Cp, Cpk, Cpm, CR)
4. Process performance indices (Pp, Ppk)

FIGURE 1. Continued.

make good BBs. Another important advantage of BB training is that it formally teaches an overall process of improvement (DMAIC). This is the glue that holds together the individual tools and facilitates solving real problems effectively. As noted by numerous authors (e.g., Hoerl and Snee 1995), such an overall approach to improvement is rarely taught in statistical curricula, whether in industry, academia, or the statistical portions of the CQE. Six Sigma should not be equated to a collection of tools!

On closer examination, then, a comparison between CQEs and BBs begins to look like an "apples to oranges" comparison. The CQE is *educated* in a broad subject-matter area—quality engineering. The BB is *trained* to perform a specific task—lead a Six Sigma project to achieve tangible results. Most CQEs are in the quality profession for the "long haul," while most BBs plan to move into other areas in a couple of years. I would suggest that neither certification is better or worse than the other, but that they are two different programs for two different purposes.

One would likely value CQEs for *what they know*, while valuing BBs for *what they can do*. Of course, most CQEs would argue that they can do a lot. I am not claiming they can't, I am only claiming that the CQE criteria do not require that they can. Similarly, most BBs would argue that they know a lot about quality management in general. Again, I am not suggesting they don't, I am only suggesting that such general knowledge will not be developed in a typical BB curriculum. Of course, the knowledge that a CQE possesses would be valuable in a BB. For this reason, organizations may consider CQEs as likely candidates for BB positions. While admitting that the CQE body of knowledge would be valuable to a BB, I must also point out that, as previously noted, knowledge of the tools is only one requirement for a BB to perform well. Other skills are also needed. In other words, there is an intersection between the skills of BBs and CQEs, but there are considerable differences as well. Therefore, holding a CQE certification should neither preclude nor guarantee selection as a BB.

Comparison to a Typical MS in Statistics

Much of the above discussion applies here, in that most MS degrees, even applied MS's, are not intended to measure someone's ability to achieve tangible results leading improvement projects. Therefore, the comparison is again an "apples to oranges" comparison. However, I briefly comment on how the BB curriculum compares to a typical MS in applied statistics. While there is wide variation in MS programs, it would be safe to say that a general applied MS in statistics includes one or more courses in each of the following:

- Probability theory
- Mathematical statistics
- Modeling/regression
- DOE;

with additional course work in some subset of the following (non-exhaustive) list:

- Non-parametrics
- Statistical computing
- Response surface methodology
- Sampling
- Time series analysis
- Reliability
- Bayesian methods
- Statistical process control
- Multivariate analysis
- Bio-statistics
- Statistical consulting.

While a BB will have the equivalent of four semester courses in statistics, the MS will likely have about twelve. Hence there is little comparison here, on either a depth or breadth basis. The "foundations" of probability and mathematical statistics are particularly noteworthy in their absence from the BB curriculum. Even a BS or BA program in statistics would likely require a much stronger theoretical background than that of a BB, and more breadth. I note again, however, that a typical MS degree does not measure one's ability to achieve tangible results leading improvement projects. I therefore believe that a BB does not have to be a "mini-statistician" to perform his or her role effectively. In addition, I regrettably believe that most statistics graduate students leave school without ever having been formally trained in how to link the individual tools together into an overall approach to improvement. In less applied programs, an MS or Ph.D. student may leave graduate school without ever having actually applied the tools that he or she studied in such detail to a real problem.

Other BB Development Issues

As noted previously, there are other issues in developing BBs beyond their technical training. In this section I briefly discuss selection of BBs, the need for mentoring, and the impact that the BB role will likely have on their careers.

Ideas on Selection of BBs

As I've stated earlier, the job description for a BB is one that requires application of Six Sigma tools to achieve business impact. Therefore, when searching for a BB candidate, the desirable qualities include a mix of technical aptitude, leadership skills, and "soft skills" such as meeting management. Of these, the leadership skills and the ability to deliver results are typically weighted highest within GE. Of course, technical skills are required to learn and apply the Six Sigma tools (those with weak technical backgrounds often struggle during training). In short, the ideal candidate will be a respected "go-getter" with a technical foundation and will be a team player. Since the BB is intended to be a developmental assignment, a huge fringe benefit is that the BB will take this knowledge and experience to all his/her future positions. In this way, a critical mass of statistically literate engineers, financial analysts, etc., can be created across the company. Therefore, readiness for career advancement within their own function is also a key criterion in selecting BBs.

The Need for Mentoring Beyond Training

I have spent most of this article discussing the formal training that should be given to BBs in a Six Sigma organization. I would like to emphasize here, however, that I feel formal training is only a part of the development that a BB requires. Often, we get feedback on our training such as: "I understand the tools when they are explained in class, but don't see the opportunities for application in my work;" or "the examples you show in class are powerful—how did those people think to use the tools in that way?" So, while I have focused the discussion here on the formal training appropriate for BBs, I feel that a bigger piece of their development comes in one-to-one mentoring specifically targeted to their projects. This is needed to help them to understand how and when they can apply that training to what they do every day. Significant time needs to be allocated, typically by the MBBs, to one-on-one development time with the BBs.

Impact of BB Role on Career Paths

One of the things that has contributed to the success of Six Sigma at GE is the way in which CEO Jack Welch has linked it to leadership development. Specifically, he recently stated in the 2000 GE Annual Report (available electronically at www.ge.com):

> "It is a reasonable guess that the next CEO of this Company, decades down the road, is probably a Six Sigma Black Belt or Master Black Belt somewhere in GE right now, or on the verge of being offered—as all our early-career (3-5 years) top 20% performers will be—a two-to-three-year Black Belt assignment. The generic nature of a Black Belt assignment, in addition to its rigorous process discipline and relentless customer focus, makes Six Sigma the perfect training for growing 21st century GE leadership."

Note that Jeffrey Immelt has been named Welch's successor as CEO, hence the "next CEO" mentioned above will be Immelt's successor. It should also be pointed out that in earlier quotes Welch had referred to the necessity for everyone to be GB trained for promotion. This latter statement is clearly in support of BBs, emphasizing the importance of this full time developmental role. Clearly then, people in GE were motivated from the very top level of management to take BB positions. This type of endorsement allows for high selectivity of people going through the BB roles. Without this support for the position and without the conviction from potential candidates that doing this job would contribute to their careers, there is unlikely to be the pipeline of qualified candidates required for these roles. With this support, however, BBs are not likely to be "raided" by competitors launching Six Sigma initiatives, since these BBs are typically looking forward to career advancement in their original function. They generally do not view themselves as career BBs.

Within GE, there is (as noted above) a clear intention to use the temporary assignment as a BB to develop future business leaders who will have a "continuous improvement" mindset. It is not intended to be oriented towards those who would consider themselves to be statisticians or quality professionals. While setting up permanent, or even extended, BB assignments could be done, such a move would generally restrict the candidate pool to statisticians, quality professionals, or the like, and would totally miss the benefits associated with developing a statistically literate critical mass of business leaders. I do not recommend such an approach.

Summary

I believe that Six Sigma has earned the amount of "press" that it has been receiving simply because it has delivered tangible results. Part of the price to be paid for the "press" is that Six Sigma may become a "buzzword," used in a vague sense to represent any use of statistical methods. This is unfortunate, since while Six Sigma makes heavy use of statistical tools, it cannot be equated with a collection of tools. A key reason why Six Sigma is not just a collection of tools is the critical role of the Black Belt in the overall implementation strategy. The tools are clearly not new, but the way in which they are implemented and supported is new.

Debating the merits of Six Sigma relative to other improvement initiatives is perfectly appropriate. However, in their discussion of Six Sigma authors should be explicit about what they mean by Six Sigma, and in particular, what their operational definition of the Black Belt role is. I hope that this discussion clarifies the type of development and qualifications that a Black Belt should have. I further hope that the differences, as well as the similarities, between the Black Belt and the CQE criteria have been clarified. I believe that there is a unique and complementary place for both roles in the quality profession.

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Key Words: *Black Belt, Certified Quality Engineer, Master Black Belt.*