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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.*

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Discussion

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We thank Dr. Hoerl for an interesting and informative presentation of how Black Belts (BBs) are trained at GE. His insights are particularly valuable, as GE has received wide visibility in the business community for their Six Sigma activities. In our discussion we focus on some aspects of how the Six-Sigma initiative was developed and implemented at Motorola, offer some comments on training and education for BBs, and provide some discussion on the evolution of a BB program within a company.

The Six Sigma program at Motorola was introduced as a customer satisfaction program aimed at reducing variability in products and services. Six Sigma was first and foremost a quality philosophy that aligned employees towards a common goal of trying to achieve virtual perfection in everything. The statistical aspects of Six Sigma involved identifying, reducing, and controlling variation. The individuals who led the projects were engineers and industrial statisticians who had in-depth process knowledge and a firm grasp of the appropriate statistical methods. These individuals had received training in statistical methods from a variety of sources including Motorola University, outside seminars, and consultants. Some of them had been formally educated in industrial statistics in colleges and universities. Indeed, ON Semiconductor, a Motorola legacy company, currently requires that BBs take 15 credits of university graduate-level statistics courses as part of the initial qualification program. The currently recommended courses are Design of Experiments, Response Surface Methods, Regression Analysis, Statistical Quality Control, and Principles of Quality Management. These organizations recognize the value of individuals who are highly trained in statistical applications and can apply that knowledge to solve problems that have impact on the business.

Identifying the individuals who should become BBs is a critical element of the program. Motorola and ON Semiconductor believe that BBs need to be recognized experts in their chosen discipline. In addition, these individuals need to show the ability to apply the appropriate statistical methods to projects and to demonstrate the interpersonal skills which allow them to lead teams, mentor and coach others, and work with senior managers to identify new opportunities for improvement. Another requirement for the BB is continuing education. It is recognized that the initial educational program can provide a solid foundation for the individual, but that on-going learning is essential. Possibly, the Level II and Level III courses that Dr. Hoerl describes would be appropriate for this. In Motorola and ON, learning about the application of statistical thinking for purposes of operational improvement is not necessarily con-

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sistent with a two-year assignment in a career path. Successful BBs have risen in the ranks and typically hold positions of responsibility and authority within the company. Part of their success has been their ability to continually foster a culture that is focused on reducing variability with the end result of customer satisfaction.

In the early days, success was easily demonstrated. There was a lot of "low hanging fruit," or problems that could be immediately improved by collecting data and using simple graphical and statistical methods to identify the sources of variability present. It is safe to assume that any company which initiates a Six Sigma program will realize some return on investment in the first few years of the program simply by focusing the employees on a common goal of improvement and working on problems that have significant immediate gains. However, it is important for companies to keep a strategic focus relative to their BB programs. It will become imperative that existing BBs receive on-going education in statistical methods to keep their skills current and to develop new ones, so that they can solve the more complex problems that will undoubtedly arise once the low hanging fruit has been picked.

The role of the Master BB is one that Motorola has only recently recognized. The ideal Master BB within Motorola is an individual who has advanced and has specialized training in applying statistical methods to not only industrial but business and organizational problems as well. The Master Black Belt is a senior BB with more than five years of experience and a proven track record of success. Master BBs are recognized as a strategic asset to a business unit and must be recommended for recognition by at least two Vice Presidents. Master BBs are much more than project leaders. They work with senior management to identify the business critical gaps in the organization, and they then lead the teams or mentor the individuals who can narrow those gaps.

Dr. Hoerl presents a comparison of his recommended BB curriculum with the body of knowledge (BOK) for the ASQ CQE certification. We agree with his comment that this is not a perfect comparison, as the curricula are different in both purpose and scope. The ASQ website (www.asq.org) also gives a Six Sigma BB Certification BOK that is summarized in Table 1 of the discussion by Dr. Bailey. It would also be useful to compare Dr. Hoerl's recommended curriculum to the ASQ BB BOK. Our impression is that the ASQ BB curriculum is broader and shallower than the one outlined by Dr. Hoerl.

Dr. Hoerl also makes some comparisons to a typical MS program in statistics. He observes that a typical BB will have the equivalent of about four semester courses in statistics. He notes that this is not a valid comparison, on either a depth or breath basis. Certainly across the MS curriculum, this is true. However, we don't think that very many, if any, industrial training courses are as effective as a good university course.

Let's take design of experiments (DOX) for an example. It seems that most of week three in the BB curriculum is devoted to DOX. If the participants work 16 hours per day, that's about 80 hours of immersion in DOX, not including any follow-up reading, study and application (and we would expect quite a bit of this, considering the role that DOX seems to play in many of the BB application projects that we have seen). For comparison, consider the semester-length introductory graduate-level DOX course for engineers and chemical/physical scientists offered at ASU (students in the MS statistics program also frequently take this course). This course consists of approximately 40 lecture hours, and the students are expected to spend between three and five hours outside of class for every lecture hour. This does not include studying for the two term exams and the final exam (four hours of examination total), or carrying out the term project, which consists of working in a team to plan, conduct and analyze an experiment and prepare a final report. Intermediate reports are required during the pre-experimental planning process as well. The "industrial version" of the academic DOX course is an intensive course that takes between six weeks and two months to complete, but it lacks the depth and to a large extent the breadth of the university course.

There are several things about the BB program that we think are very good. Specializing the training for individuals with different backgrounds and/or responsibilities is excellent. We would like to have more information about specialized efforts for individuals from manufacturing, engineering design/development, and other R&D functions (for examples), as these represent important functional areas of a business that are usually good candidates for BB projects. We also commend GE for requiring formal examinations to measure mastery of the course material. Many industrial training programs seem more concerned with course participant satisfaction than their actual understanding of the concepts.

Companies should seriously consider university courses as a component of their overall educational activities for BBs and Master BBs; certainly these courses should be part of the continuing education for these individuals. Most industrial courses are *training* courses, and the BB curriculum and the description of how it is packaged and delivered seems to fit that definition nicely. However, education differs from training in that it is more likely to include the reasons *why* things work as opposed to simply *how* they do, and to instill capabilities of generalization and extension. Individuals with this kind of capability are essential once the low-hanging fruit mentioned earlier is harvested. Perhaps it is time to start thinking about education of the future generations of BBs and Master BBs.

It is unfortunate that universities have not been given real opportunities to participate in Six Sigma programs. Certainly not all universities have the faculty interests and capabilities or students to provide a basis for involvement in industrial activities, but there are some academic programs that can certainly provide useful assistance and that would be interested in fostering effective working relationships with corporations pursuing Six Sigma objectives. Moreover, this represents an opportunity to bring industry and academia together with great potential benefits for both. Universities are developing the industrial statisticians of tomorrow (and those who will use statistics extensively in their work, even if they are not degreed statisticians), and if industry wants to positively impact the education that these individuals receive, then it has to be willing to *actively* engage with the academic programs. There are many avenues for this, and there are academic programs that would be very effective partners, but few companies are making the effort.

Finally, we remember several notable past failures to implement company-wide quality improvement and variability reduction activities, including value engineering, zero defects, and various incarnations of total quality management (TQM). These efforts failed for a variety of reasons, but an issue was that they were unable to successfully focus on achieving practical, measurable business results. Six Sigma has succeeded, at least in part, because it has been able to do this. If continued success is to be enjoyed we can't stand still; it is necessary to improve, expand, and continue to develop the scope and concepts of the effort. It is with this spirit that we offer our comments.

Discussion

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Introduction

WE would like to congratulate Dr Hoerl for providing a lucid account of what a Six-Sigma Black Belt needs to know and a practical, tested approach for delivery of this knowledge. Given his experience and the success of the Six-Sigma improvement methodology at General Electric, it is difficult to be overly critical. Nevertheless, in the spirit of continuous improvement, we offer the following comments and suggestions. Note that we restrict our comments to the statistical tools and methods that a BB needs to know and leave discussion of the other, likely more important, skills to others. We also believe that ongoing high level management support and motivation are the most important drivers in a successful implementation of an improvement process such as Six Sigma. The importance of the statistical details of the curriculum pales in comparison.

Our perspective on the issues raised in Dr. Hoerls' paper is a product of our own experience. We are both academic statisticians who have spent our working careers in a university statistics department. Fortunately, we have been involved extensively for the last 16 years with improvement programs, applying statistical methods and statistical thinking to a wide variety of problems within many different frameworks that mirror DMAIC. Most of these problems have been in a high-volume manufacturing context. We have taught industrial short courses on many statistical topics. We have substantial experience in helping candidates prepare for the CQE examination. One of us (JM) managed to pass the CQE examination.

However, we have no direct experience with implementing Six Sigma so our comments must be taken accordingly. We have separated our presentation into three categories: the proposed curriculum, the comparison to the CQE program, and the comparison to a Master's program in statistics.

The Proposed Curriculum

Because of our experience, we feel most qualified to discuss the curriculum proposed for an organization with a manufacturing orientation (see Table 4 in Hoerl's paper).

In terms of the overall structure, the proposed curriculum has two important features. First, the embedding of statistical methods and tools within a framework such as DMAIC has a strong impact on the understanding of, and interest in, the methods themselves. For example, it is fascinating to compare, holding the instructor fixed, the reactions of a class of MS students to that of a group of practicing engineers when they are first exposed to the ideas of factorial experimentation.

The second key feature, not shown explicitly in Table 4, is the use of relevant examples and, even better, a concurrent project to demonstrate the utility of the methods. The examples provide a strong motivation to grasp the concepts. The project provides immediate opportunity to practice what we find is the most difficult aspect to teach—the selection of the appropriate approach, method or tool at any point in the project.

The statistical details of the curriculum in Table 4 are more difficult to discuss because little information is provided on the depth and breadth with which topics are covered using the "What-Why-How sequence". However, we offer some specific comments.

The notions of sampling or more generally, strategies for data collection are critical to the success of the training. This topic deserves to be pervasive in the curriculum. Students must learn to make decisions on what data to collect, how to collect them and how to ensure their integrity. Most projects will involve a sequence of studies, each with its own data collection issues. Should an experimental or observational plan be used? When is it important to mea-

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sure a certain explanatory variate on each sampled part? Over what time frame should the sample be collected? Asking and answering these and a myriad of other similar questions related to the data collection requires statistical judgement and knowledge. It is our view that these issues should be thoroughly discussed within the proposed curriculum.

We think that the early inclusion of control charting as a way to establish a baseline for process performance is an excellent approach. The continued construction of the chart during the project can demonstrate the effect of incremental improvements and after the project is closed, the chart can be used to verify that the improvements can be maintained. We would argue that this is the major reason for including charting in the curriculum and that, for the most part, feedback control methods should not be based on control charts. We would suggest replacing the element SPC Part II in the Control section of the curriculum by an introduction to process control as in Box and Luceño (1997) We see little value in the use of control charts to isolate causes of variation and so recommend limiting discussion of control charting to the initial section. See Steiner and MacKay's (2000) discussion in Woodall (2000) for more a detailed argument of this point.

In terms of traditional formal statistical analysis, we support the idea that confidence intervals should be emphasized over hypothesis tests whenever possible. There is a large risk of confusing statistical significance with the practical significance of an effect. The confidence interval gives an immediate picture of the size of the effect. Intervals for parameters such as regression coefficients need to be expressed in terms of the size of the mean shift when the explanatory variate is shifted by a fixed amount. We have found that combining ANOVA with the graphical analysis of complex multi-vari studies to be very helpful in isolating important families of variation. The notion of an analysis that generates components of variation fits well with CTQ flow-down and flow-up tools.

For the Analysis phase, we also highly recommend a discussion of a strategy to find the root cause(s) using a series of observational studies to eliminate families of causes and to progressively narrow the search. This approach has been promoted by Dorian Shainin as described by Shainin (1992). We prefer to teach many of the analysis tools within the framework of this strategy. For problems with high volume manufacturing processes, this is a powerful approach that should be included as part of the curriculum.

In summary, we find the proposed curriculum and its method of delivery highly appealing. Is there a lesson here for those of us who spend most of our statistics teaching time in the university classroom?

Comparison to CQE Body of Knowledge

As Dr Hoerl points out, comparing the CQE body of knowledge to the proposed curriculum for BB training is like comparing apples to oranges. However, if we look at the statistical content only, there is a great deal of overlap in the topics, if not in the manner of learning. We would like to comment briefly here on assessment. The ultimate test for a BB is the successful leadership of completed projects. There is no corresponding method of assessment for the CQE. The examination is the only CQE assessment vehicle.

Unfortunately, Dr Hoerl provides us with no examples of questions that are used on the test that immediately follows the BB training. However, he does state that the purpose of the examination is to test comprehension of the material. We can look at the flavor of the CQE examination by studying the sample questions provided with the study guide for the prescribed body of knowledge. The CQE examination is open-book with essentially no limitations. Consider the following questions which have been reformatted and renumbered from the ASQ webpage (www.asq.org/cert/types/cqe/studyguide.html):

1. Which of the following tests may be used to determine whether a sample comes from a population with an exponential distribution?

   (a) t
   (b) F
   (c) Chi-square
   (d) ANOVA

2. Which of the following tools are appropriate for a quality engineer to use in qualifying a process that has variable data?

   I. An $\bar{X}$ and R control chart
   II. A histogram
   III. A c chart
   IV. A p chart

   (a) I and II only
   (b) II and III only
   (c) III and IV only
   (d) I, II, and IV only

3. The correlation coefficient for the length and weight of units made by a process is determined to be 0.27. If the process were adjusted to reduce the weight of each unit by 0.5 ounce, the correlation coefficient of the length and weight of the units made by the new process would be equal to
   (a) 0.50
   (b) 0.27
   (c) 0.23
   (d) −0.23
4. To determine the average number of nonconforming parts over time, which of the following attribute control charts would be most appropriate?
   (a) c chart
   (b) np chart
   (c) p chart
   (d) u chart

These questions do not examine comprehension and do not provide the appropriate emphasis that is present in Dr. Hoerl's curriculum. The first question is unanswerable without some knowledge of how the data are collected. The second question can be answered knowing only that c and p charts are used for discrete data. The third question can only be answered by assuming that the adjustment does not effect the joint distribution of the length and weight. With different assumptions, all the answers are possible. None of the charts in question 4 are particularly appropriate for determining the "average number of nonconforming parts over time", a poorly defined process characteristic.

We suspect that learning to deal with such questions will provide the CQE candidate with little help in using statistical tools and methods for BB improvement projects. As noted above, we have helped many CQE candidates prepare for the examination in the past. The preparation is largely teaching key word recognition, tricks for answering multiple choice questions (e.g. eliminating answers in question 2 above) and methods for indexing resource materials so that answers can be found quickly. Comprehension and ability to apply the methods on the job are low on the list of goals for the course. For further emphasis of our point, we refer the reader to Wortman (1999), a widely used resource for examination preparation.

The point of the above diatribe is to further emphasize the differences in the approach to the CQE and Six Sigma curricula. We strongly believe that the approach is far more important than is the detail of the curriculum topics.

Dr. Hoerl unfortunately did not compare his proposed curriculum to the body of knowledge for the ASQ Six Sigma certification examination (www.asq.org/cert/types/sixsigma/bok.html). We worry that the ASQ body of knowledge and the associated testing will generate the same abuses as described above for the CQE examination. The statistical content of the body of knowledge is very formal. Some obvious contrasts are the heavy emphasis on hypothesis testing with little mention of confidence intervals. More importantly, the surrounding framework seems to play a very small role. It will not be possible to tailor the learning to a local environment. The curriculum is a shopping list of statistical tools. We do not believe that self-study of such a curriculum will produce BBs who can lead successful improvement projects. The potential saving grace is that a candidate must have successfully completed one or two projects before writing the examination.

Comparison to Masters in Statistics Curriculum

We agree with Dr. Hoerl's lament that many graduates of a master's program in statistics may successfully complete the program without ever applying the tools to a real problem. However, many programs encourage students to become involved in statistical consulting with clients drawn from graduate students in the empirical sciences. At Waterloo, we have had difficulty managing such a process and have resorted to extensive role-playing as a poor substitute. Even in such artificial situations, we find it sobering to watch highly-rated graduate students struggle with the simple, but poorly specified, problems posed by their clients.

A second issue is the lack of framework for teaching statistical methods at both the graduate and undergraduate level. Having seen the success of surrounding the teaching of statistics with a framework such as DMAIC, we have attempted a similar approach especially in introductory courses. Most applications of statistics are to areas other than process improvement. What they all share is that an empirical approach is taken to learn and action may or may not be taken on such learning. Lawless (1999) provides a more detailed description of statistical activity. We have built a framework to teach and to apply statistical methods within this context. The framework has five steps, Problem, Plan, Data, Analysis and Conclusion (PPDAC), each of which has several sub-steps. This framework fits within DMAIC when, for example, it is decided to determine a baseline measure of performance for a process or to investigate the effects of several factors on a response. Each time we set out to learn more about the process through collecting and analyzing data, we are using PPDAC. Making the framework explicit has many ramifications for the teaching and learning of statistics. For more detail, see MacKay and Oldford (2000).

Conclusion

We again congratulate Dr. Hoerl for a stimulating discussion of the BB curriculum and thank the editor for providing an opportunity to discuss this issue.

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Discussion

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So What's Going On?

As usual, Roger Hoerl has given us an insightful article on an important topic. I find little with which to disagree. My comments are in addition to what Hoerl has said, and focus on the forces that produce the need for the type of training and tools he discussed.

It is important to recognize first that the needs of the business determine what Black Belts need to know. These business needs identify the roadmaps and tools that Black Belts need to:

- Create effective, efficient, and rapid improvements that are linked to the bottom line.
- Make effective use of computing technology.
- Work in different environments.
- Serve in different roles.

I will comment on the needed roadmaps and tools later. We must also pay attention to how the tools are presented during training in order to foster an effective learning process.

The forces placing demands on our corporations are the same that create the need for Six Sigma improvement. Understanding these forces helps us define the technical skills needed by Black Belts. The first important force is global competition, which raised its ugly head in the late 70's and early 80's, strengthened during the 90's, and is not likely to go away at least as long as there is peace in the world. This has added another task to our list of things to do. We now have two jobs: to *do* our work of serving our customers and to *improve* on how we do our work (Hoerl and Snee (2002)).

It is the job of the Black Belt to help the organization improve on how it does its work. But the Black Belt can't do it alone, and there are other members of the organization working with the Black Belt on improvement. This takes resources away from the "doing" activities, those daily work activities we do to serve our customers. I note in passing that this need to do the additional job of "improving" creates both the need for cultural change and the associated resistance which develops in response in most organizations.

For Black Belts to be successful, they must have a set of tools that enable them to quickly solve a broad range of significant problems so that the involved resources are used effectively. Their function is to improve process performance in such a way that the bottom line is enhanced. Black Belts, therefore, need tools that enable them to rapidly create improvements that produce significant bottom line results.

The second important force is easy access to powerful, easy-to-use computer hardware and software. Computers have become more and more ubiquitous, and this technology must be integrated into Black Belt training so that Black Belts have access to the technology and learn how to use it most effectively. I believe that the availability of effective, easy-to-use computer technology is one of the key reasons for the effective use of Six Sigma in such a diverse array of companies, cultures, and business functions.

Black Belts Work In A Variety of Environments

The type of training Black Belts should receive is a function of the environment in which they work. Key factors are the *type of company* (manufacturing or service), *type of function* (operations, transactional, administrative, or new product development), and *type of industry* (assembly, processing, chemical, etc.). The trick is to understand the environment in which the Black Belt is working (including the processes that will be the focus of their work) and design the training accordingly.

In service companies, the customer is typically closer to the processes used to serve the customer, and it becomes necessary to relate customer measurements to the operational process variables in or-

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der to identify opportunities for improvement. This need also exists in manufacturing, but it takes on a different form because of the greater distance between the customer and the manufacturing process. Black Belts need some different tools to operate in these two different environments.

The tools required to improve manufacturing and non-manufacturing processes are similar but have some important differences. Gage R&R studies of measurement systems are of less value outside of manufacturing. However, attribute Gage R&R studies are useful in assessing attribute measurements used in non-manufacturing environments (Automotive Industry Action Group (1995)). The most useful non-manufacturing metrics are defects and errors (lack of accuracy, correctness, completeness), cycle time, cost, and customer satisfaction. Since measurement systems are typically less well developed outside of manufacturing, Black Belts in these environments need to know how to develop useful measurement systems and how to collect relevant data.

Some believe that design of experiments is less useful outside of manufacturing and R&D. Designed experiments are certainly used less today in non-manufacturing environments than in manufacturing and R&D, but I believe that this lack of use is due to lack of understanding of the value of the tool. The use of designed experiments will continue to grow in the non-manufacturing area as we learn how to better use the tool in this environment. Koselka (1996) discusses several non-manufacturing examples of designed experiments.

In the case of new product development, greater use is made of design of experiments, including robust design and statistical tolerancing techniques. There are also a number of non-statistical tools used in new product development applications of Six Sigma, also know as Design for Six Sigma.

Chemical and process industries make greater use of design of experiments, response surface methodology, time series analysis, etc. than do the assembly industries. These differences also find their way into the Design for Six Sigma methods used for new product development.

Role of Black Belts

The technical skills required by Black Belts are also a function of their role in the organization, their intended career paths, and the relationship of Black Belts to Green Belts and Master Black Belts. In general, Master Black Belts mentor and teach Black Belts, and Black Belts in turn mentor and teach Green Belts. Those Master Black Belts and Black Belts that do teaching will, in general, need a deeper and broader knowledge of the tools. Effective teachers typically have skills and knowledge at least one level deeper than the material they are teaching.

Some organizations emphasize the leadership and managerial roles of the Master Black Belt, while other organizations emphasize both the leadership and technical roles of the Master Black Belt. In some organizations, Master Black Belts also lead "mission critical" projects. The technical role requires a broader and deeper knowledge of the tools. Additional technical skills that are needed can be obtained through train-the-trainer sessions. It is far better, however, to develop this knowledge as part of the Black Belt training by including project applications so that a deep understanding of the tools and methods is developed. Some organizations find it helpful to give their Black Belt additional training in the use of advanced tools.

Training Issues

There are some training issues that deserve further comment. First, we need to recognize that the job of the Black Belt is to do something to make processes better. This expectation is for the project used in the training as well as for all projects on which the Black Belt works; therefore, in all aspects of the training the emphasis should be on improvement. Training is for building the skills needed for doing the improvement work (Snee (2001b)). The project selected should be important to the business. The term "training project" should not be part of the Six Sigma vocabulary. The importance of project selection suggests that the Black Belt will need some training on project selection, collection of baseline measurements, determination of process entitlement (the best performance the process can be expected to attain, e.g. 100% yield, zero waste, $0 cost of failure), and the construction of a framework for calculation of the financial value of the project (Snee (2001a)). While this work is done in collaboration with the finance department, there are many statistical issues involved that the Black Belt should be skilled in handling.

Another training issue is the matter of accelerated training; for example, doing a 4-week Black Belt curriculum in 2 weeks. This approach is limited because it overlooks the large amount of material Black Belts

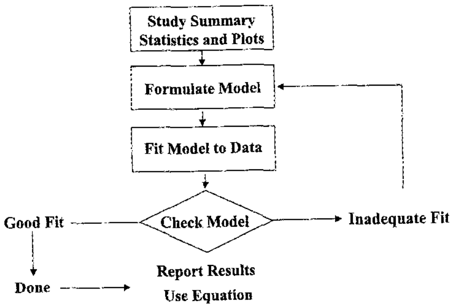

FIGURE 1. Regression Analysis Method.

need to know to do their jobs, the fact that learning is not a linear process, and that this approach allows less time for project work and project review by the Master Black Belt trainers. If the 4 weeks of training is a concern then we should look for alternatives. Regardless of the method chosen, it is important to question whether the approach will provide the knowledge, skills, tools, and experience that the Black Belt needs to quickly, effectively, and efficiently create the process improvements desired by the organization. We must not forget that Six Sigma is about improvement, not training per se. Overemphasis on training is a low yield strategy (Snee (2001b)).

It is also important in the presentation of the tools to provide roadmaps and step-by-step procedures for each tool and overall methods. A method for doing regression analysis is shown in Figure 1 (Hoerl and Snee (2002)) which depicts the 5 key steps in the process. There are 5-7 sub-processes within each of these steps. Such aids help the Black Belt move up the learning curve more quickly. I believe that part of the appeal of the Taguchi design of experiments approach is the availability of step-by-step procedures to implement the proposed methods.

Using the Six Sigma Tools

It should also be noted that, while most Six Sigma tools are not new, some aspects of how the tools are used are new or at least different. Two tools that come to mind first are Failure Modes and Effect Analysis (FMEA) and Control Plans. FMEA has been used in process design for many years, but, in the past, FMEA has not been used for process improvement. In this sense FMEA is a new tool for process improvement. Control Plans have also not been part of most improvement processes in the past.

Characteristics of Six Sigma that make it effective are the integration of the tools with the DMAIC improvement process and the linking and sequencing of the tools. The integration of the tools is shown in Tables 2-4 of Hoerl's article, but the linking and sequencing of the tools is less apparent. Black Belts move up the learning curve much more quickly when they can see the sequence in which the tools are to be used and how the output of one tool becomes the input of one or more other tools.

In the case of the process industries, there needs to be greater emphasis on the variation introduced by sampling processes. In the process industries, variation in the process output is due to the process and all its inputs, the sampling process, and the measurement system. Gage R&R studies only consider the measurement system. Components of variation studies are needed to evaluate the methods used to sample the process (Box, Hunter, and Hunter (1978), ASQ Chemical and Process Industries Division 2001, Snee (1983)).

Statistical process control (SPC) and Control Plans, parts of most Black Belt training, are being introduced near the end of the training. I have found it effective to introduce SPC (or at least the use of time plots of key output variables) and the Control Plan in the first week and then return to these topics for a more in-depth discussion in week 4 of the training. This use of SPC gets the Black Belt focused on the key output variables and the associated baseline variation and its effects.

The Control Plan summarizes the key findings of the project and provides key information on how to run the process. By introducing the Control Plan early, "we begin with the end in mind" and enable the Black Belt to see where the project is headed (Covey (1990)). This approach provides the Black Belt with clear direction on what needs to be done to finish the project. The Control Plan is built as the project is conducted, and is finalized in the Control Phase of the project.

There needs to be greater emphasis on recognizing that human intervention in a process is often an important source of variation and on providing tools to deal with this issue. Hoerl notes that mistake-proofing is an effective tool for improving manufacturing processes. Process robustness is an approach in which changes are made to make the process insensitive to uncontrollable variation (Snee (1993)). Mistake proofing, and process robustness in general, are important tools for improving both manufacturing and non-manufacturing processes, particularly for dealing with variation introduced by human interventions, and should be part of the Black Belt curriculum.

Advanced Tools Are Needed in Some Applications

Hoerl points out the need for tools beyond those covered in a 4-week Black Belt training session. I have seen this need as well. The advanced tools required depend on the area of application. Almost all Black Belts can benefit from more training in regression, multi-vari studies, and screening experiments. In addition, depending on the area of application, Black Belts working in the process industries also benefit from more training in design and analysis of process sampling methods, process variance components, cumulative sum process control, principal component analysis, general linear models, test method ruggedness, mixture experimentation, and data mining.

Training of Engineers

I also note that the roadmaps and tools of Six Sigma are effective in dealing with all types of processes. This suggests that this methodology should certainly become part of the training of all process engineers and other engineers when needed. The associated skills will make them much more effective problem solvers and process designers.

I will conclude by recalling Shewhart's (1939) admonishment that:

> "The long-range contributions of statistics depends not so much on getting a lot of highly trained statisticians into industry as it does in creating a *Statistically Minded* generation of physicists, chemists, engineers and others who will in any way have a hand in developing and directing the production processes of tomorrow." (emphasis added)

I believe that training Black Belts as described by Hoerl, and the use of the Six Sigma approach in general, takes us a long way toward developing the statistically-minded workforce Shewhart envisioned in 1939.

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Discussion

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I wish to thank Roger Hoerl for an excellent piece of work. The title of his paper does not really do justice to the content. In fact, the paper discusses not just what Six Sigma Black Belts need to know, but how they are to acquire and use this knowledge. The author has covered this broad scope admirably.

The point of this paper, as I understand it, is to operationally define the term "Black Belt." It is important to note that this is not a trademarked term, although there have been efforts in the past to make it one and despite some claims by ASQ to the contrary.

Before Training: Candidate Selection Criteria

The article addresses the specific skill set needed by Six Sigma Black Belts. This presumes that successful candidates have already been chosen for training. The author discusses this late in the paper and concludes that, within GE, leadership skills rather than technical skills are given the greatest weight. Leadership skills are defined as the ability to deliver results. But how does one determine that candidates can deliver results *before* they become Black Belts? Table 1 gives the criteria I recommend to my consulting clients.

The weights in Table 1 are my own subjective evaluations from pairwise comparisons using the analytic hierarchy process (AHP). I have developed a model where each of these items is evaluated and scored for each candidate and an overall score calculated. I believe that GE's criteria "ability to deliver results" is closely related to my category "ability to overcome obstacles." However, I find it easier to evaluate a candidate's ability to overcome obstacles *a priori* than their ability to deliver results. To do so, I present various problem scenarios to the candidate and ask them to offer alternatives to reaching a goal (this also helps us assess the candidate's oral and verbal communication skills). Some individuals, when faced with an obstacle in a simple scenario, can't think of any alternatives. For these people, providing tools to help guide them around obstacles (e.g., force field analysis, PDPC, FMEA, etc.) is not enough. Often these candidates are highly successful at their jobs, intelligent, personable, and quite likable. Remember, most people work at jobs that don't require them to deal with obstacles. They are given duties to perform and they are evaluated on how well they carry out their routine assignments. Obstacles are few, and those encountered are usually reported to superiors for action. The Black Belt's job is that of change agent, and a significant component of the job involves getting people over whom you have no authority to change. It takes a very special person to do this job well.

I place math skills last on my list because Black Belts have abundant resources to draw upon for help in this area. In addition to their statistical software, they also have other Black Belts, Master Black Belts, and often corporate statisticians. As Hoerl notes, Black Belts will seldom have the in-depth skills of more highly trained data analysts even after their training. Thus, most Black Belts will need to make frequent use of these resources. In addition, experts in statistical analysis examine all Black Belt projects closely as the projects are conducted and feedback is provided. It would be unfair to ask a newly trained and inexperienced Black Belt to conduct complicated technical analysis without this assistance. Remember, most Black Belts are only on the job for two or three years. Even the most "experienced" Black Belt is a novice when it comes to statistical or financial analysis of their projects. Although math skills are not heavily weighted, I do require that candidates get a passing score on a simple math test at the level of high school algebra. Shockingly, about 60% to 70% fail this test, including many degreed engineers and financial analysts.

The Role of a BB?

Hoerl describes the role of the BB by means of a

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series of examples. All of the examples involve improving important business processes. The measures of success are as follows: improved download time for a web page, preventing lapses for unprofitable policies and encouraging lapses for unprofitable policies, and improved customer satisfaction. All three measures are quantified based on their impact on revenues or costs.

TABLE 1. Recommended Criteria for Evaluating Black Belt Candidates

Criteria	Weight
Able to overcome obstacles	34.3%
Attitude towards Black Belt job	22.4%
Logical thought process	12.4%
Communication skills (oral and written)	9.4%
Use of facts and data	8.5%
Team experience	6.7%
Math skills	6.3%

These examples dramatically highlight a key difference between Six Sigma and traditional quality improvement. None of these projects are designed to have an impact on what would normally be called "quality." The focus is not on defects, non-conformance to requirements, scrap, rework, returns, etc. This expanded use of the tools of "quality improvement" into other areas of the company is, I think, very exciting. In an earlier response to this paper, I pointed out that Six Sigma is a new way of managing an organization and that the BB role is entirely new. To my knowledge, there has never before been an official, temporary, and full-time position focused entirely on improving business processes. The BB (and Master Black Belt) position creates organizational slack that makes it possible to change the business at a revolutionary pace. However, this broader role also means that many quality professionals find themselves left out when it comes to selecting BBs. I have encountered more than a few bitter CQEs who feel that Six Sigma undervalues their expertise. To an extent, I agree. As pointed out by the author, there is a lot of overlap between the CQE's skill set and that of BBs, but there are differences as well. Many CQEs can't see beyond their parochial interest in quality. Others find it impossible to break away from their old paradigms, which view Six Sigma as a collection of tools, or DPMOs, or some other narrow perspective. ISO 9000, with its focus on standardization and limiting changes in options, has contaminated the thinking of many quality professionals. The BB role requires that people think like entrepreneurs serving customers rather than like technologists or bureaucrats enforcing standards. For many quality professionals, the transition is simply too difficult.

Reporting Relationships for BBs

Although more research is needed, there is anecdotal evidence showing that it is preferable to have BBs report to a central organization rather than to their home organizations. It seems that it is simply too difficult for BBs that stay in their home organization to break away from their normal duties. A colleague, the Director of Six Sigma for a company reputed to be one of the leaders in Six Sigma, told me that she tried both centralized and decentralized reporting relationships and kept statistics on the BBs. Her data showed that BBs who reported centrally had an 80% probability of successfully completing multiple projects and becoming certified. This compared with a 40% probability for BBs reporting to local management. A colleague whose company had centrally reporting full time BBs and locally reporting part time BBs (50% commitment) believed that only about 20% of the part-time/locally reporting BBs made it through the company's certification process.

If the company's senior leadership isn't aggressive, then it is sometimes difficult for even centrally reporting, full-time BBs to disengage from their routine duties. Most companies provide a phase out period of about six months from the start of BB training for the new BB to extricate himself or herself. Still, I know of at least one case where candidates had to obtain letters from the CEO to break free. The difficulty of taking the best people out of an organization where they are star contributors must not be underestimated. BBs should not be expected to handle this aspect of their role by themselves.

BB Effectiveness Criteria

I have been working with Bryan Dodson and a group of interested members of the International Quality Federation (IQF) to develop a body of knowledge for BBs. Space does not permit a complete presentation of this here (see www.pyzdek.com for detailed information.) The criteria reached by the IQF are, in broad terms:

1. Passing the IQF BOK exam.

2. Acceptable completion of a black belt training curriculum approved by the candidate's Sponsoring Organization.
3. Demonstration of clear and rational thought process.
   a. Ability to analyze a problem following a logical sequence,
   b. Usage of facts and data to guide decisions and action.
4. Be able to clearly explain Six Sigma and the DMAIC project cycle in layman's terms.
5. Ability to achieve tangible results, e.g.,
   a. Completion of two or more projects that employ the Six Sigma approach (DMAIC or equivalent).
      i. Projects reviewed by appropriate personnel.
      ii. Deliverables accepted by the project sponsor.
      iii. Projects documented in the manner prescribed by the Sponsoring Organization.
      iv. Projects that correctly employ a significant subset of basic, intermediate, and advanced Six Sigma tools and techniques (see web link above for a listing of these tools and techniques.)
   b. Ability to perform benefit/cost analysis,
   c. Ability to quantify deliverables in terms meaningful to the organization, e.g., cost, quality, cycle time, safety improvement, etc.,
   d. Ability to identify and overcome obstacles to progress,
   e. Ability to work within time, budget, and operational constraints.
6. Demonstration of ability to explain the tools of Six Sigma to others.
7. Demonstration of interpersonal and leadership skills necessary to be an effective change agent within the organization.

Candidates are evaluated by means of a set of questionnaires answered by supervisors, peers, project sponsors, MBBs, champions, and others. Successful candidates are co-certified by the IQF and their own organizations as Six Sigma Black Belts.

It is likely that any candidate who completes and understands the curricula presented in Tables 2 or 4 of Hoerl's article would be able to successfully pass the IQF exam. However, those exposed only to the materials in the GE Finance-Oriented Curriculum presented in Table 3 of Hoerl's article would likely have difficulty.

This highlights an important point, namely that it is probably not possible to answer the question posed by the title of the paper. The answer to the question "What do Six Sigma Black Belts need to know?" is "that depends." I've seen a successful Six Sigma program where a financial services division of a large firm had a paucity of technically qualified people to be BBs. Their solution was to provide two weeks of training, then create about twice as many MBB positions as usual (the ratio was 1 MBB per 5 BBs). The solution was very successful. The same company had a large aerospace R&D operation that was rich in technically trained people. R&D provided six weeks of training for BBs and had relatively few MBBs. The duties of these MBBs emphasized development of support systems (e.g., project tracking software, enterprise data systems, etc.) rather than the traditional mentoring role for BBs. Again, the approach was an unqualified success.

Discussion

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As one who has been involved in Six Sigma for 6 1/2 years at AlliedSignal, now Honeywell, I think that Roger Hoerl has done an excellent job of describing the role of Black Belts (BBs) and comparing their development and curricula with other models such as MS programs and CQE requirements.

Although BBs in the early stages of Six Sigma were largely from manufacturing and engineering functions, it is refreshing and appropriate to illustrate BB projects from the administrative areas where there are many processes in need of attention and improvement.

The sample curricula are similar to those that I am familiar with, although the sequence of the introduction of topics may differ from one program to the next. Obviously, a curriculum must meet the customer's needs, that is, the business functions that are being served and have processes in need of improving. The author has addressed this well. Most of the tools in the tool kit of the proposed curriculum are exactly those needed by most BBs. Using Roger's proposed curriculum in his Table 4 as a basis, I would like to offer some additional tools, their sequencing, and training approaches for increasing the effectiveness of BBs in driving results to the bottom-line. This is based on the AlliedSignal/Honeywell experience that has had a Six Sigma impact in savings of $2.6 billion since the end of 1994.

The tools that I will be referring to have added extra insight to the Define, Measure, Analysis, Improve, and Control phases of the DMAIC roadmap. These include: Thought Process Maps (TMAP), Process Mapping, Cause & Effect matrix, and Failure Modes and Effects Analysis (FMEA) in Week 1; subjective measurement systems and components of variation (COV) in Week 2; a "front to back" exercise in week 3; and special concentration tracks in Week 4 depending on the BB's area of focus.

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The TMAP (Hild et al (1999)), as the term suggests, provides a list of questions that the BB and his/her team need to ask and answer in order to find the information required to improve a process. These questions often follow sequences in parallel paths highlighting the steps and tools that will be needed to collect and analyze the data. The sequences follow the DMAIC roadmap and thus provide the BB a logical path for problem solving and tool deployment. When the TMAP is one of the tools used in the Define phase, key questions are addressed early.

At Honeywell, we have found process mapping to be an essential tool for assessing the process under study, including documentation of the key process input and process output variables (referred to as KPIVs and KPOVs) at each step in the process. For prioritizing the process steps and KPIVs, a Cause & Effect matrix has proven to be an effective tool. The C&E matrix helps to identify those variables that need to be studied in detail in an FMEA and later in Design of Experiments (DOEs). This combination of process mapping, Cause & Effect matrix, and FMEA (which is currently included in the Improve phase in Roger's proposed curriculum) belongs in the Measure/Analyze phases. This effective sequence of tool deployment is taught at Honeywell in week 1 of a 4 week BB curriculum, enabling the BB to focus early on the process steps, key input and output variables, and the related failure modes that will have the most impact on process improvement.

In week 1, just as Roger suggests, we set the foundation for Six Sigma and the reduction in variation by providing an overview of the "what" and "why" issues, and we reinforce these lessons with exercises that illustrate the issues related to variation.

As part of the Measure phase, in addition to the measurement system evaluation with variables data, we also address subjective measurement or attribute data with the introduction of Kappa and Intraclass Correlation (ICC) assessment tools (Futrell (1995)). We are finding high levels of application both in the manufacturing and in the transactional function type projects. These are very important for BBs to know and understand since "go/no-go" data or subjective data (such as "good," "better," "best" expressed as ordinal data) may be the only measures they have.

Another tool that we have found very important, and that is not mentioned by Roger in the proposed curriculum shown in Table 4, is the time or spatially dependent Components of Variation (COV) analysis. This appears in Honeywell's BB Week 2 when the Analysis phase is discussed. Here the BB gets a solid appreciation of the hierarchy of variation, say, for example, across time from lots, batches within lots, samples within batches, and measurements within samples.

Other features of the Honeywell BB program that address some of the important characteristics stressed by Roger include a "front to back" exercise in Week 3 after the BB has gone through all core training material plus a fourth week of concentration related to the function from which a BB has come. The exercise in Week 3 goes on during the whole week, with teams of BBs competing at designing, operating, and marketing a new missile-like product using the DMAIC roadmap and many of the tools learned in the first 3 weeks. The teams compete on the final day of week 3 to see which has the best-performing product (i.e., can hit a target with minimum variation). This usually requires a full deployment of most tools in the DMAIC toolkit, including a prediction model developed through DOEs which are the main subject matter of Week 3.

Week 4 is a concentration week where a BB can select a "track" specifically suited to his/her project and discipline area. The tracks include chemical/polymer continuous processes (CPP), discrete manufacturing, administrative processes, product design (or Design for Six Sigma (DFSS)), and market/customer research (MCR). Here, additional new tools and applications are introduced geared to the particular needs of the BB's area of project application. For example, multivariate data analysis is discussed extensively in the CPP track addressing the many relationships among input and output variables that typically are recorded on chemical processes. Tools like cluster, discriminant, factor, and conjoint analyses plus quantitative surveys are covered in the MCR track to help address issues of market segmentation and the assessment of customer interests in certain product attributes.

A feature of the curriculum and its deployment that is not directly addressed by Roger, but that is taken very seriously in the Honeywell program, is the learning environment itself. First, the class is led by a team of two or three Master Black Belts (MBBs) who *facilitate* the discussion rather than lecture. "Air time" by the facilitators is recommended to be less than 40%. This provides for more involvement by the class, more discussion, and clearer answers to questions. Each new subject has a practical, graphical, and analytical component, or "PGA," to further help with the "what," "why," and "how" of a new tool.

Each MBB goes through extensive training on how to facilitate in this kind of environment. There are lots of breakouts of small teams to address questions, with feedback given to the whole class, plus time to work examples at their tables using Minitab. Our classes are typically made up of 25-30 BBs (vs the 15-50 in the GE classes as mentioned by Roger) which makes this learning environment work very well. Our experience is that if the classes are larger than this, then the interaction and BB involvement will drop off. Time is also planned for in each week of classes for project reviews by the facilitators. This helps keep the BBs on track in their deployment of the DMAIC phases of the projects. AlliedSignal/Honeywell has trained more than 4000 BBs using this format.

It should be noted that all BB Six Sigma training is performed with a common set of material. That is, the training material is overseen by a committee of MBBs from across different businesses and the corporate director of Six Sigma. Changes in the material must be approved by this curriculum committee. The classes are made up of facilitators (i.e., MBBs) and BBs from across the corporation to provide for diversity of representation from different functions, projects, and business products. Having a common set of material and a certification process adds to the consistency in the knowledge base of BBs. It is only in week 4 that the BBs move into different cohorts to specialize on a track closest to their discipline. The facilitators are encouraged to add examples from personal experience that emphasize why the material is important.

As for Master Black Belts, they can be defined differently depending on the company. At GE, they have a more managerial or supervisory role than at Honeywell, where they are change agents, project leaders, and tool masters. Both models have worked effectively in the companies mentioned. In both cases, the MBBs have had a large impact on driving results to the bottom line through their mentoring of BBs on projects, training BBs, and helping to select the right projects and BBs to work on them.

At Honeywell, MBBs must be certified BBs to start with and then must go through a rigorous development process, that averages 15 months, for certification. As part of their development, they receive additional statistical ("deep dive") training related to the Six Sigma tool set, are given training in facilitation skills, receive leadership training, and complete a project that typically exceeds $1 million in impact to the bottom line. (Note for comparison: Honeywell BB projects are typically about $250,000 in business impact, although some have been in the millions of dollars in savings). The technical "deep dive" material draws heavily on tools that George Box and his colleagues have introduced into the quality community (Tiao et al. (2000)). The MBB's competency relative to his/her training skills, technical skills, and organizational impact is scored and compared to expected standards before certification can be granted by the MBB's certification review committee. A formal corporate wide certification process is followed and used to certify the MBBs.

Six Sigma, arguably, has had the largest impact of any modern Total Quality programs, since it is focused on processes, variation reduction, and delivering quantitative financial results. These results have most often been tied to productivity, growth, and revenues in major corporations. Roger Hoerl has given the reader a very comprehensive picture of one of the instrumental players in the process, the Black Belt along with his/her role and development.

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Discussion

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We would like to thank Roger Hoerl for writing a very informative article which describes the required skill set and development plan for a Six Sigma Black Belt (BB). While there is much that we (Smarter Solutions) agree with, there are also some key differences.

There are two basic aspects to the skill set of a BB: intrinsic skills that are used to help select BB candidates and skills that are gained or improved through training. Concerning intrinsic skills, Hoerl writes that "... when searching for a BB candidate, the desirable qualities include a mix of technical aptitude, leadership skills, and 'soft skills.'" We agree that these elements are very important. In addition, we have highlighted a couple of other important characteristics for this selection process. These characteristics are:

- Fire in the belly: an unquenchable drive to improve products and processes.
- Ability to manage projects and reach closure: a persistent drive toward meaningful bottom-line results and timely completion of projects.

We would also like to commend Hoerl for his recommended BB curriculum. A number of the topics coincide with an agenda that we have suggested for successful Six Sigma training (see Breyfogle (1999) and Breyfogle, Cupello, and Meadows (2001)). Hoerl recommends, and we can say from experience, that they work well. Some of the highlights of areas where we agree with Hoerl are:

Overall

- Presenting the big picture in the first week.
- Using student projects.
- Integrating software within each topic.
- Using the DFSS type of tools for determining process specifications for key process variables.

Define phase

- Giving detailed attention to project selection and scoping.
- Starting the development of process thinking.

Measure Phase

- Addressing the issue of process stability through the use of high-level off-line control chart metrics on key process output variables (see Breyfogle and Meadows (2001)).
- Discussing how data quality is critical in this phase, because the measure of the process baseline and improvement all hinge on capable measurement systems.

Analyze Phase

- Detailing how graphical and statistical tools are critical to understanding how a system is behaving.

Some of the topics where we differ with Hoerl include:

The Role of the Black Belt

- Hoerl defines the BB's role as mostly operational. We contend that BBs should also play a key role in the strategic aspect of implementing Six Sigma within a business. BBs should have a good working knowledge of the organization and details of the processes occurring within their assigned departments. When selecting and scoping projects, BBs should serve as a voice of the workers who live the processes. If Champions and MBBs are the only voices heard when defining projects, the system functions in a similar manner to old-style manufacturing environments, where the designers "threw their designs over the wall" to manufacturers with little mutual dialogue, team learning, or consensus.

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When Teaching Statistics

- We have a difference of opinion on how to teach the concepts of statistical analyses. We do agree with Hoerl that we are not trying to make statisticians out of BB candidates. We also agree that the use of confidence intervals is a more enlightening approach than hypothesis testing, and that p-values are a good way to introduce BBs to conducting statistical tests. However, Hoerl indicates that the most important part of their statistical training is how to properly interpret the computer output. We believe that the understanding of sampling variation is the most important aspect of their statistical training. Sampling variation is not theoretical abstraction, but rather a fundamental underpinning of interpreting and understanding the implications of computer output. Without this understanding, how can BBs explain the fact that two different samples may have different sample means, but that the statistical tests do not indicate that the differences are statistically significant? It is possible that Hoerl means to include sampling variation when he suggests teaching the "why" of statistical tests, but we think that this is too important not to specify as a critical course requirement for BBs. Sampling variation can be a difficult concept to grasp, and it is one of the main reasons that people misunderstand statistical results. Fortunately, the idea of sampling variation can be easily demonstrated through the use of computer simulations, which we recommend and use throughout the four weeks of BB training to augment hypothesis testing and confidence interval discussions.

Again, we would like to thank Roger for addressing this important topic. The question of what constitutes a BB's skill set and how it differs from a statistician's or CQE's is common. Roger has done a good job of answering this question as well as addressing the type of training and mentoring a BB should receive.

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Discussion

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WHEN I read Roger Hoerl's paper, my reaction was like that of basketball sportscaster Marv Albert watching a steady stream of three-pointers being made. In other words, I kept saying "Yes!" after every paragraph, reaching new personal levels of "violent agreement." Thus, I will focus my brief remarks on the following three areas:

1. DuPont's experience with Six Sigma as it relates to the major points in Hoerl's paper;
2. The complementary roles of the quality professional, the statistics professional, and the various "belted" six sigma professionals; and
3. The recently published Body of Knowledge (BoK) for Black Belts from the American Society for Quality (ASQ).

DuPont and Six Sigma

DuPont decided to implement Six Sigma within its Specialty Chemicals (now DuPont Chemical Solutions Enterprise) business in late 1998, then globally expanded this implementation to all businesses starting in early 1999. Initial reactions ranged from enthusiasm to skepticism, with the latter mood reflected in comments such as the following:

1. "We're doing this already!"
2. "This won't work in our business!" For example, one business that prided itself in having each person in the organization own not only the "operate" and "maintain" functions of a process but also the "improve" and "renew" functions was worried about segregating the "improvers" and "renewers" into a Black Belt community.
3. "This too shall pass," as have other so-called "programs of the STP (short time period)." (Pick you favorite STP... day, week, month, quarter, or year).

But as we complete our third year of this effort, there is an increasing awareness and experience base that shows the following:

1. Six Sigma is providing a focus and framework for doing several orders of magnitude more improvement work (based on quality technology and applied statistics) than we have been doing, and moreover, for providing the financial rigor to track its impact to the bottom line.
2. With proper adaptation and a "can-do" attitude, we are making Six Sigma the way we work in our businesses.
3. With attention to not only productivity improvements but also top line growth (e.g., via Design for Six Sigma), we will rightfully be driving this initiative for the long(er) haul. This is an important point that GE's incoming CEO Jeffrey Immelt made when he spoke to our corporate leaders: "keep it fresh."

There was considerable variability in the initial fifty waves of Black Belt training that were provided by nearly two dozen different instructors. This was true even though the instructors in theory adhered to the learning objectives set out by our Six Sigma training provider who contracted them. It was only after we started our own internal Green Belt training that we achieved some standardization, including fleshing out of the DMAIC roadmap. Hoerl refers to GE's finance-oriented BB training as being the two-week GB curriculum plus an added week of topics. What has been Hoerl's experience in training incoming BBs who have already had GB training?

The Professionals of Quality, Statistics, and Six Sigma

Figure 1 shows a conceptual Venn diagram of the overlapping Bodies of Knowledge for the quality professional (as perhaps embodied by the Certified Quality Engineer), the professional statistician (at, say,

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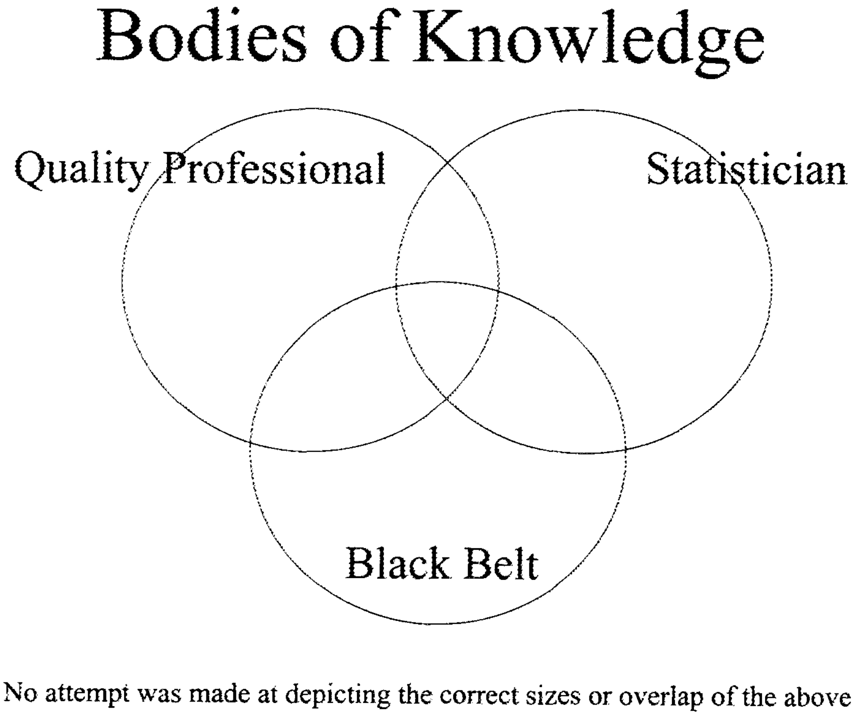

FIGURE 1. Venn Diagram of the Overlapping Bodies of Knowledge.

the Masters level discussed by Hoerl), and the Six Sigma Black Belt. Note that I have not attempted to fill in the areas of overlap and distinctness.

But besides the "bodies of knowledge," we have in DuPont "knowledgeable bodies" (i.e., the workforce) in every part of this diagram, including the overlaps. There are plenty of opportunities along the entire operate/maintain/improve/renew spectrum for contributions from individuals anywhere in this diagram. I hope Hoerl's words don't get twisted into "those that do are BBs, and those who can't do are quality professionals or statisticians." In particular, of those BBs without the prior background of being a quality or statistics professional, the more highly effective BBs are able to identify projects for which the statistician or quality professional will be a valuable addition to their project teams.

The ASQ Black Belt Body of Knowledge

ASQ has been involved in certification for a third of a century since its introduction of the CQE in 1968. ASQ has a proven process of gathering the voices of the experts and the voices of customers in developing the body of knowledge for a given certification. They also have a proven methodology for developing and administering examinations. Representatives from nearly every major Six Sigma training provider (the experts) were involved up front in the BB BoK draft development process, and a diversity of Six Sigma practitioners were involved in finalizing the BoK and the rest of the process steps. The resulting BoK is shown in Table 1, with each item in this breadth of knowledge assigned a corresponding level of depth according to the six levels of Bloom's Taxonomy shown in Figure 2. Thus, this BoK has both breadth and depth.

Of course, healthy discussion continues to ensue on other aspects of certification.

1. To be certified, do you have to take some type of full-fledged "six sigma training" (vs. some refresher training or learning the body of knowledge on your own)? Of course, even with four full weeks of BB training, it is very challenging to cover the entire BoK.
2. What is the best way for testing mastery of the body of knowledge?
3. How many projects are required to be completed (and at what cumulative financial threshold) before certification?

In addition to ***content*** specifics, the subtext detail also indicates the intended ***complexity level*** of the test questions for that topic. These levels are based on "Levels of Cognition" (from Bloom's Taxonomy, 1956) and are presented below in rank order, from least complex to most complex.

Knowledge: (Also commonly referred to as recognition, recall, or rote knowledge.) Being able to remember or recognize terminology, definitions, facts, ideas, materials, patterns, sequences, methodologies, principles, etc.

Comprehension: Being able to read and understand descriptions, communications, reports, tables, diagrams, directions, regulations, etc.

Application: Being able to apply ideas, procedures, methods, formulas, principles, theories, etc., in job-related situations

Analysis: Being able to break down information into its constituent parts and recognize the parts' relationship to one another and how they are organized; identify sublevel factors or salient data from a complex scenario

Synthesis: Being able to put parts or elements together in such a way as to show a pattern or structure not clearly there before; identify which data or information from a complex set is appropriate to examine further or from which supported conclusions can be drawn

Evaluation: Being able to make judgments regarding the value of proposed ideas, solutions, methodologies, etc., by using appropriate criteria or standards to estimate accuracy, effectiveness, economic benefits, etc.

FIGURE 2. The Six Levels of Bloom's Taxonomy.

It is very helpful, however, to have what I think will become viewed as the benchmark document from which to start.

It should be noted that the ASQ Statistics Division gave some serious consideration in the 1990's to sponsoring a "certified statistician" but chose for various reasons not to do this. And, as Geoff Vining in his 2000 Youden Address and others have noted, an opportunity area exists for universities to pick up the challenge in producing BBs, or at least GBs, especially if connected to effective intern programs.

In conclusion, let me thank the editor for giving me the opportunity to comment on this paper.

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TABLE 1. ASQ Six Sigma Black Belt Body of Knowledge

I. Enterprise-Wide Deployment (9 Questions)	II. Business Process Management (9 Questions)
A. Enterprise view	A. Process vs. functional view
1. Value of six sigma **C**	1. Process elements **AN**
2. Business systems and processes **C**	2. Owners and stakeholders **AN**
3. Process inputs, outputs, and feedback **C**	3. Project management and benefits **AN**
B. Leadership	4. Project measures **AN**
1. Enterprise leadership **C**	B. Voice of the customer
2. Six sigma roles and responsibilities **C**	1. Identify customer **AN**
C. Organizational goals and objectives	2. Collect customer data **AP**
1. Linking projects to organizational goals **C**	3. Analyze customer data **AN**
2. Risk analysis **C**	4. Determine critical customer requirements **AN**
3. Closed-loop assessment / knowledge management **C**	C. Business results
D. History of organizational improvement/foundations of six sigma **C**	1. Process performance metrics **AN**
	2. Benchmarking **K**
	3. Financial benefits **AP**
III. Project Management (15 Questions)	**IV. Six Sigma Improvement Methodology and Tools—*Define* (9 Questions)**
A. Project charter and plan	A. Project scope **S**
1. Charter/plan elements **AN**	B. Metrics **AN**
2. Planning tools **AP**	C. Problem statement **S**
3. Project documentation **S**	
4. Charter negotiation **AN**	
B. Team leadership	
1. Initiating teams **AP**	
2. Selecting team members **AP**	
3. Team stages **AP**	
C. Team dynamics and performance	
1. Team-building techniques **S**	
2. Team facilitation techniques **AP**	
3. Team performance evaluation **AN**	
4. Team tools **AP**	
D. Change agent	
1. Managing change **AP**	
2. Organizational roadblocks **AP**	
3. Negotiation and conflict resolution techniques **AP**	
4. Motivation techniques **AP**	
5. Communication **AP**	
E. Management and planning tools **AP**	

TABLE 1. Continued

V. Six Sigma Improvement Methodology and Tools—*Measure* (30 Questions)	VI. Six Sigma Improvement Methodology and Tools—*Analyze* (23 Questions)
A. Process analysis and documentation 1. Tools **AN** 2. Process inputs and outputs **E** B. Probability and statistics 1. Drawing valid statistical conclusions **E** 2. Central limit theorem and sampling distribution of the mean **AP** 3. Basic probability concepts **AP** C. Collecting and summarizing data 1. Types of data **E** 2. Measurement scales **AP** 3. Methods for collecting data **E** 4. Techniques for assuring data accuracy and integrity **E** 5. Descriptive statistics **AN** 6. Graphical methods **E** D. Properties and applications of probability distributions 1. Distributions commonly used by black belts **E** 2. Other distributions **AP** E. Measurement systems 1. Measurement methods **C** 2. Measurement system analysis **E** 3. Metrology **C** F. Analyzing process capability 1. Designing and conducting process capability studies **E** 2. Calculating process performance vs. specification **E** 3. Process capability indices **E** 4. Process performance indices **E** 5. Short-term vs. long-term capability **E** 6. Non-normal data transformations (process capability for non-normal data) **AP** 7. Process capability for attributes data **AP**	A. Exploratory data analysis 1. Mutli-vari studies **AP** 2. Measuring and modeling relationships between variables a. Simple and multiple least-squares linear regression **E** b. Simple linear correlation **E** c. Diagnostics **AN** B. Hypothesis testing 1. Fundamental concepts of hypothesis testing a. Statistical vs. practical significance **E** b. Significance level, power, type I and type II errors **E** c. Sample Size **AP** 2. Point and interval estimation **AN** 3. Tests for means, variances, and proportions **E** 4. Paired-comparison tests **E** 5. Goodness-of-fit tests **E** 6. Analysis of variance (ANOVA) **E** 7. Contingency tables **E** 8. Non-parametric tests **AN**

TABLE 1. Continued

VII. Six Sigma Improvement Methodology and Tools—*Improve* (22 Questions)	VIII. Six Sigma Improvement Methodology and Tools—*Control* (15 Questions)
A. Design of experiments (DOE)	A. Statistical process control
1. Terminology **C**	1. Objectives and benefits **C**
2. Planning and organizing experiments **E**	2. Selection of variable **AP**
3. Design principles **AP**	3. Rational subgrouping **AP**
4. Design and analysis of one-factor experiments **E**	4. Selection and application of control charts **AP**
5. Design and analysis of full-factorial experiments **E**	5. Analysis of control charts **AN**
6. Design and analysis of two-level fractional factorial experiments **E**	6. PRE-control **AN**
7. Taguchi robustness concepts **AN**	B. Advanced statistical process control **C**
8. Mixture experiments **AN**	C. Lean tools for control **AP**
B. Response surface methodology	D. Measurement system re-analysis **E**
1. Steepest ascent/descent experiments **AN**	
2. Higher-order experiments **AN**	
C. Evolutionary operations (EVOP) **C**	

IX. Lean Enterprise (9 Questions)	X. Design for Six Sigma (DFSS) (9 Questions)
A. Lean concepts	A. Quality function deployment (QFD) **AN**
1. Theory of constraints **C**	B. Robust design and process
2. Lean thinking **C**	1. Functional requirements **C**
3. Continuous flow manufacturing (CFM) **C**	2. Noise strategies **AP**
4. Non-value-added activities **AP**	3. Tolerance design **AN**
5. Cycle-time reduction **C**	4. Tolerance and process capability **AN**
B. Lean tools **AP**	C. Failure mode and effects analysis (FMEA) **AN**
C. Total productive maintenance (TPM) **C**	D. Design for X (DFX) **C**
	E. Special design tools **K**

Key to Levels of Cognition (see Figure 2):

K = Knowledge
C = Comprehension
AP = Application
AN = Analysis
S = Synthesis
E = Evaluation

Response

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I would like to thank all the discussants for providing their unique perspectives on this important subject. Reading them, it is clear that there are several common themes in their comments (common causes), and, in addition, some discussant-specific comments (special causes); therefore, I will organize my rejoinder by first addressing the common causes and then providing some response to discussant-specific special causes.

Common Discussant Themes

Can We Actually Answer the Question Posed?

Perhaps the most critical common issue raised by the panel of discussants is whether it is possible to provide a single correct answer to the question of what BBs need to know. Several specific problems are identified by the panel that make it difficult to provide a single correct answer:

- The needs of individual businesses ultimately determine what BBs need to know.
- The curriculum must be dynamic, not static (BB learning is a process, not an event).
- The curriculum needs to be tailored to different situations and audiences.

Each of these is a valid point, and, clearly, there is no single, correct answer to the question of what BBs need to know. The discussants are certainly correct here, and this is one reason I present both manufacturing and finance-oriented curricula. While admitting this point, I would also suggest that there must be some common roles, skills, abilities, etc. that all Black Belts have in common, or the term has no meaning. I am afraid that this is the situation now (lack of common definition), and businesses and industries are suffering from the confusion, as noted in my original introduction. I would further suggest that the best practical solution involves a common "core" BB skill set, which is dynamic over time, can be tailored to specific application areas, and is derived from general business needs (instead of technical dogma). The profession needs to reach consensus on what this common core is.

I like the Honeywell approach mentioned by Hill of having 3 weeks of common material for everyone, and then tailoring the 4th week to the individual's function or application area. To me this is a good balance between standardization and flexibility. Providing an on-going curriculum of advanced topics (e.g., multidimensional tolerancing, robust design, etc.) would also help BBs continue their skill development over time. Of course, this "common core" needs to be dynamic itself rather than etched in stone at one point in time.

Should We Even Try to Certify BBs?

A related issue is whether we should be certifying BBs at all. In the original article, I consciously avoid focusing on this question because it relates to a separate subject; however, it is raised by several discussants, and it is certainly related to the issue of what BBs need to know. A key point here is that one can only be "certified" in regards to defined, documented criteria. The tailored, flexible curriculum discussed above would require tailored and flexible certification processes. Another problem, noted by both Snee and myself, is that despite the title of the original article, BBs are not valued for *what they know*, but rather for *what they can do*. Certifying knowledge is a much easier task than certifying ability. I agree conceptually with the concept of certification, but am concerned about how to accurately measure the ability, rather than knowledge, of a BB. For example, obtaining a driver's license generally requires a live demonstration of actual driving proficiency, over and above passing a test. Requiring one or more successful BB projects helps with this issue, but in a perfect world there would be more emphasis on demonstrated abilities than test scores.

I like Pyzdek's criteria for certification (which he refers to as a body of knowledge), but I have not seen the specific details on how to measure the non-test aspects of this process. The devil is usually in the details, as is demonstrated by Abraham and MacKay with the CQE exam. In summary, I would suggest that we need to be very clear on specifically *what* we are actually trying to "certify" in the certification process. This could include abilities, knowledge, or even attitude (c.f. comments in discussion by Breyfogle et al. on "fire in the belly"). In the final analysis, I suspect this will be a tougher nut to crack than the CQE, CQA, etc., which are more knowledge-oriented certifications.

How Does the ASQ BOK Compare?

Several discussants referred to the ASQ Black Belt Body of Knowledge (BOK) and asked about comparisons to my recommended curriculum. I should point out that this material was not posted on the ASQ website at the time of my original article submission. Now that it is posted, it is certainly appropriate to compare it with my recommended curriculum. The "short answer" is given by Montgomery et al.: the ASQ BOK is considerably broader than my recommended curriculum. If it is expected that BBs will develop the appropriate level of cognition (c.f. Bailey's discussion) in the same amount of time (four weeks of training plus project work), then it must certainly be much shallower. Referring back to my original point: if the focus is, as I believe it should be, on obtaining results, then narrower and deeper is better. Just give people the ability to apply the minimal tools they need to get the job done. If the focus is on knowledge, then broader and shallower is better. I do share Abraham and MacKay's concerns that this BOK is starting to look like a "shopping list" of statistical (and non-statistical) tools. While it is certainly easier for the team working on this BOK to reach consensus if everyone's "favorite tool" is included, this has the danger of diluting the core. Combining this issue with the "dynamic versus static" issue discussed above, I feel that it makes more sense to have a narrower common core which can be augmented by individual functions or businesses.

The Importance of Sampling Variation

Several discussants mention the importance of sampling variation and the need to develop skills in BBs to determine good data collection strategies. This is an excellent point. By the way, the sampling variation mentioned by the discussants, if I understand it correctly, is not to be confused with random variation. Rather, this is variation introduced in the sampling process, as a function of how, when, where, etc., we actually collect data. This subject is rarely addressed properly in textbooks, except perhaps under the topic of nested designs, but it is critically important in practice, where we cannot simply assume all data are "random observations." I refer to this as the subject of "data quality," which is included in my recommended curriculum. However, I must admit that to some people "data quality" means identifying typos in the data, hence something like "strategies for collecting appropriate data" is perhaps a better title for this topic.

The Value of Providing a Big Picture

Another issue discussed in the original paper, and emphasized by several discussants, is the added value of having overall roadmaps for integrating and sequencing the tools. While this point may have been "beaten to death" in the article and discussion, I do not think it can be overemphasized. In my opinion, this is one of the primary reasons for the success of Six Sigma– it provides an overall approach for improvement, not just a collection of tools. The skeptics, who suggest that Six Sigma is just another repackaging of the same old tools, are missing an important point here.

I further believe that this is one of the great shortcomings of most statistical training in academia, industry, government, and so on. Students are typically taught a number of individual tools (DOE, SPC, hypothesis testing, probability, regression, nonparametrics, etc.) and leave the course with no mental "big picture," no idea of how all this "stuff" fits together. Six Sigma provides an overall process of improvement (DMAIC) that clearly shows how to link and sequence individual tools. Suddenly, students actually know what to do when faced with a real problem! The text (Hoerl and Snee 2002) mentioned by Snee is primarily motivated by this critical oversight. Of course, others have introduced their own overall frameworks or roadmaps, such as the Lawless (1999) approach mentioned by Abraham and MacKay. DMAIC is certainly not a perfect approach, it just works! Other logical approaches will also work.

Special Discussant Themes

Montgomery et al.

A key point made by these discussants is the potential missed opportunity caused by industry not partnering with academia as a component of their Six Sigma training efforts. This is an important and valid point. While GE has certainly used various individual academics to help with their training efforts, I am not aware of any true academic partnerships. As noted in their discussion, many academic institutions are either not interested or not qualified for such partnerships, but undoubtedly some are. Such institutions can help in curriculum design, classroom training, consulting on complex applications, and especially in providing continuing education opportunities for BBs.

Bovas Abraham and Jock MacKay

Two points made by these discussants on which I would like to comment are the proper role of SPC and the use of a defined strategy to find root causes. Concerning SPC, I can certainly see the value of including engineering process control concepts and tools, such as from Box and Luceño (1997), as suggested in their discussion. I do not agree, however, that Part II of SPC should be deleted. For reference, Part II focuses on formal chart construction and use (Part I is primarily conceptual). While admitting that control charts do not identify root causes of variation or help improve stable processes, they can be extremely helpful in avoiding variation induced by human intervention, as noted by Snee. In other words, control charts can be very helpful in indicating when *not* to take action, thereby avoiding knee-jerk reactions to normal variation. Of course, they are not a replacement for good engineering control schemes.

Abraham and MacKay also note the value of using a strategy for identifying root causes such as that proposed by Shainin (1992). A good, disciplined strategy will generally be better than an ad hoc approach, so I am in general agreement with this point. Just as the DMAIC approach provides an overall strategy, we can utilize more detailed and lower level strategies for each step in this overall process. This "tiered" approach, an overall big picture and more detailed strategies based on it, is the approach taken in Hoerl and Snee (2002). However, I have found the Shainin approach to be much more effective for dealing with special cause variation than for improving stable systems. With special cause variation there is typically a single root cause for the problem. Therefore, approaches based on the assumption of a dominant root cause will tend to work. With common cause variation, however, searching for the single root cause of a perceived difference can often amount to a "wild goose chase." In the text referenced above, Snee and I suggest an approach that first distinguishes between special and common cause variation and then adapts the strategy accordingly.

Ron Snee

Snee makes an interesting point that counterbalances a key comment from Montgomery et al. Just as business and industry may have missed an opportunity in not partnering with academia more, academia may be missing the boat by not including Six Sigma in academic curricula. Snee specifically suggests that Six Sigma be part of the training of engineers. I would add that business students and statisticians should also be graduating with a good understanding of what Six Sigma is all about.

Tom Pyzdek

Pyzdek goes into more detail than I did on selection criteria for BBs. I certainly agree with the basic criteria he proposes, although I would be reluctant to tell business leaders to weight a factor "22.4%." Perhaps 35%, 20%, 10%, etc., would be easier to communicate.

I would also like to highlight Pyzdek's point that Six Sigma has perhaps created the first full-time position in history dedicated solely to improving business processes, the Black Belt. Advocates of Frederick Taylor or Joe Juran might disagree, but I both agree and further suggest that this is another key reason for the success of Six Sigma.

Bill Hill

Hill makes a number of suggestions about tools to be included and integrated into BB training that deserve consideration. He also points out the importance of using "front to back" exercises in training, i.e., exercises that require students to actually integrate and sequence the tools through several rounds of improvement. I have found this to be the most effective means of teaching how to integrate and sequence tools. Hill notes that at Honeywell MBBs must come from the ranks of certified BBs. I like this in principle, but it does create an "initialization problem" that must be worked out when starting a Six Sigma initiative.

Breyfogle et al.

The role recommended for BBs by these discussants seems to include "strategic" duties that at GE have been more the concern of MBBs or Quality Leaders/Champions. This is neither right nor wrong, just different. Certainly at GE, and I think most companies implementing Six Sigma, the Black Belt role has focused on execution. Of course, to properly execute projects one needs some level of involvement in the planning that leads to selection of these projects in the first place. Their point is valid in this regard.

These discussants' comments on the importance of sampling variation were addressed above in the discussion of common themes. However, I would like to add one point in response to their statement that I am perhaps suggesting that proper interpretation of computer output is the most important part of a BB's statistical training. They suggest that understanding of sampling variation is the most important statistical aspect of this training. I actually believe that statistical thinking, i.e., the statistical thought processes that are developed in the BB, is the single most important aspect of their overall training. These thought processes include viewing all work as a process, understanding the practical implications of variation, basing opinions on data whenever possible, and the mental rigor required to utilize a systematic, disciplined approach to improvement. The tools are relatively easy to convey if you can develop this mental discipline of statistical thinking first.

Steve Bailey

Bailey makes a strong case for the ASQ BB BOK, which I have commented on above. He also provides a Venn diagram showing that there are both similarities and areas of uniqueness between CQEs, BBs, and statisticians. I certainly agree with this diagram. Another noteworthy point is the experience DuPont initially had with "nearly two dozen" instructors from their Six Sigma provider. Theoretically, this should add a lot of variation to the process, and according to Bailey this is exactly what happened. Those organizations getting into the Six Sigma game should ask a lot of detailed questions of providers about specifically what they are getting for their money.