Adult Learning in an Industrial Setting

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This paper presents an evaluation of a statistical training program which took place at a Ballarat industrial plant throughout 1996. The success of this program, and others throughout America and Europe, has far reaching implications for the way in which we teach statistics in undergraduate courses at tertiary institutions. This paper examines the success of the program in the light of adult learning models and outlines the direction of on-going studies into the effectiveness of such training programs.

Introduction

During 1996 an industrial company quietly embarked upon a specialised statistical training program at their Ballarat plant as part of an overall program initiated by their parent company in America. The training program, which was designed to increase process yields, reduce the cost of poor quality, and to increase capacity through the use of statistical tools, was delivered by a group of consultants from the Six Sigma Academy based in Phoenix, Arizona.. The objectives were to train people to support major process improvement projects and to become proficient in basic and advanced Total Quality Management (TQM) tools.

The training format comprised 5 sessions varying from 3.5 to 5 days in length. Each session used the *plan, train, apply and review* methodology that has been so successful in similar programs conducted in America and Europe. The topics covered included *descriptive and inferential statistics, process improvement planning, failure mode and effects analysis, process capability studies, measurement system analysis, gauge reproducibility and repeatability studies, multi-vari studies, experimental design (DOE), and statistical process control and tolerancing.*

Use of computers formed an integral part of the training. Each participant had personal use of a Pentium laptop, and all were expected to become proficient in Word, Excel, Powerpoint and Minitab. While some aspects relating to these packages were dealt with during the course of instruction, most participants spent many extra hours at home refining their skills.

Participants were also expected to begin training with a work place project clearly identified. In most cases these projects were related to scrap or defect problems resulting from current processes from the factory floor. These projects were the focal point of the training program, and varied in scope and complexity. Having been allocated a project the participants task was to solve the problems associated with the particular process involved. The projects dealt with such problems as *the failure of gaskets to bond adequately, inconsistent densities from a moulding operation, the presence of scratch marks on metal backing plates, curvature of backing plates,* and so on.

Trainees worked on these projects either individually or in pairs. Usually the required result was to reduce scrap or defects by 50%. Successful certification after completing the training was dependent upon the trainee being able to demonstrate command of the appropriate statistical techniques with their application toward success on the selected project.

Financial and Educational Success

For the Ballarat company, as well as others who have embarked upon similar training, successful results have certainly followed. The company have estimated that the training projects alone have resulted in savings of $800 000. Further evidence of the success of the program is seen in the numbers of employees that have volunteered for similar training in 1997. The company is in the fortunate position of having a healthy pool of volunteers from which to select their trainees, thereby creating a premium on positions for this training program. Phase one of company planning will be to ensure that every engineer employed at the plant receives this training. The next phase will be to make the training available to shop floor managers, and so on.

There are probably many reasons for the current successes being reported around the world, resulting from training programs such as that undertaken at the Ballarat plant. The implications for how and what we currently teach in our undergraduate courses at University level should not escape our attention. I feel there are four major reasons for the successes reported. The first has to do with the power of the statistical content while the second concerns the learning model embodied in the structure of the training program. Other reasons have to do with company commitment and participant expectations.

i) Statistical Content:

A major focal point of the content was the use of carefully designed experiments involving *Multi-variable testing*. Multi-variable testing techniques allow experimenters to change many variables simultaneously. Traditionally engineers have experimented with the production process by methodically changing one factor at a time and analysing the results. Such a procedure has been shown to be both inefficient and costly in terms of resources and time, as well as being incapable of detecting interactions between variables that often are primary causes of problems in manufacturing processes.

Properly designed experiments where several variables are altered at once are highly efficient in that more use is made of the data collected thereby reducing the number of tests required to isolate the problem. Such experiments are more capable of readily identifying those variables having the greatest impact upon a process as well as the effects of any significant interactions that may exist between these variables.

Statistical analysis provided the tools that enabled the participants to determine those variables considered to be significant factors. Design of Experiment (DOE) techniques provided an opportunity to further refine the list of significant variables and to focus upon an optimal operating window within which process yields and capacity could be maximised, and the costs of poor quality reduced. The material is not new and techniques involving multi-variable testing have existed for many years. However, the power of modern computing software has made much of the analyses more accessible and may well have to do with the growing awareness and acceptance of such data analysis.

Allowing for Process shift: Another challenge to traditional thinking that arose from this particular training program was the concept of allowing for the natural drift of any process mean over time. Research has shown that typically a process mean will shift by a factor of 1.5 times the process standard deviation (Evans 1975). The implications of this with respect to process control directly challenges the traditional concept of process variation in relation to specification limits. Traditionally the objective has been to attempt to keep process variation to about one-sixth of specification width. Allowing for maximum process drift this amounts to 66807 defects per million opportunities. Current best practise throughout the world is to maintain process variation at one-twelfth of specification width, which translates to 3.4 defects per million opportunities, again allowing for maximum process drift.

To what extent in engineering courses offered around Australia is there reference to multi-variate Design of Experiment techniques, or to the statistical tools required for their analysis? To what extent is there reference to procedures for analysing measurement system capability or to the implications of shifts and drifts in processes? In some instances the mathematical and statistical content of our engineering courses has been reduced and yet we have a situation where manufacturing industries around the world are spending hundreds of thousands of dollars putting in place training programs to re-train their engineers in the statistical procedures required so that they can remain competitive. Clearly more time and effort is required on our part to at least pay heed to these trends and to develop accordingly.

ii)The Training Program as a Model of Learning:

My first impressions with regard to the educational worth of the training program were mixed to say the least. Beginning each day at 7:30-8:00am., and continuing until 4:30 or 5:00pm. and maintaining this over a four or five day period was daunting to say the least. Everybody who participated including the instructors was exhausted at the end of each day with the effort of concentration that had to be maintained.

As mentioned previously, successful training programs in America and Europe have made use of a methodology involving the cycle *plan, train, apply* and *review*. This fits very nicely into what education theorists call the Action Research Spiral (see Fig.1 below) which can be described as following the path of *plan, act, observe, reflect, replan, ...*

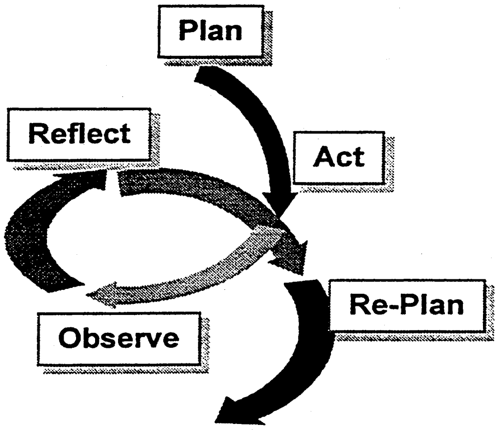

Figure 1: Action Research Spiral

The training program itself was an excellent example of action research being put into practice. It was designed to generate process improvement experts who learn by doing (the heart of the training program involved a project directly related to processes in current operation). Once trained these *experts* are expected to share their training with fellow employees, to continue the cycle anew, and so beginning the development of a culture leaning towards what Oakland would call total quality management.

The learning model adopted by the instructors involved *lectures, course notes, materials and handouts, worked examples, practice examples, hands-on computations, case studies, self review, simulations, application projects and presentations.* The program was structured in such a way that in any 3 or 4 hour period most of the aspects mentioned above would be experienced. For instance, instead of participants completing a set of practice exercises by themselves, one exercise would be allocated to 2 participants who were then required to work together as a team to solve the problem. Solutions and explanations were then presented to the whole group using Powerpoint with appropriate Minitab output inserted as required. Questions from the floor were always encouraged. At first this proved very daunting, to say the least, however, participants soon realised that no matter what they thought they were being heard, it was OK to be wrong and it was OK to ask for help.

This was a model that promoted a deep approach to learning. Throughout the training considerable emphasis was given to

- relating existing knowledge to the project in hand;
- drawing on knowledge from as many sources as possible via project teams;
- placing theoretical statistical ideas into the realm of shop-floor experience;
- relating and distinguishing between evidence and argument - *there is no argument if you have no data* was a common catchphrase.

These points typically characterise the deep approach to learning espoused by Ramsden (1992) and Biggs and Moore (1993).

Characteristics of Adult Learning: An important factor contributing to the success of this training program was that it accounted for the major characteristics that typify adult learning. Roberts (1986) identified five main characteristics of self-directed learning activities for adults. Each of these characteristics were readily identifiable throughout the training program at the Ballarat plant. Table 1 below presents a summary of Roberts' characteristics, with brief explanations of how each was apparent in the training program.

Table 1: Characteristics Typifying Adult Learning (Roberts)

Learning is usually episodic rather than continuous;	*The structure of the training program was such that it took place in concentrated bursts - train for a week, work with it for 3 weeks, train for a week, work with it for 3 weeks.*
Learning is generally aimed at the solution of immediate specific problems of a concrete rather than theoretical nature;	*At all stages of the training examples were brought in directly from the factory floor. Identification of the projects (focal point of the training) was made using specific problems that currently existed in the plant which required an immediate fix.*
Learning is rarely pursued in a systematic way;	*This was more subtle to detect, however it became apparent by observing how participants worked towards solving the problems associated with their particular projects.*
Knowledge from many sources is usually used to solve particular problem (not confined to specific discipline areas);	*The emphasis placed upon establishing an effective team was both strong and consistent. A good team was one that represented all layers of personnel associated with the particular process. Successful projects were often associated with effective teams.*
As material is mastered it is applied immediately	*Again, the structure of the training program ensured this would occur using the one week to learn the material and three weeks to apply the knowledge before the next learning episode.*

iii) Commitment of Company Management:

Undoubtedly an important factor in the success of such training programs is the degree of commitment shown by senior management. The Bulletin (July 16 1996) quotes Mikel Harry (founder of the Six-Sigma Academy) as saying the "key to the process is a company that is prepared to accept change and devote its entire thinking to quality control at every step of production".

Previous successful programs have required the commitment to quality at all levels, and particularly at the senior levels. At the Ballarat plant this was given due emphasis by the senior-level appointment of a *Project Champion*. This responsibility was taken on by the manager of Quality Control, whose role was to devise and oversee each participant's project, and, most importantly to protect participants from negative criticism from above and below.

Total Quality Management: The structure of the program was such that it brought together the essential elements of total quality management, which according to Oakland (1993) and Caulcutt (1995), include *commitment, culture, communication and co-operation.* I feel that this was also a major contributor to the success of the program. A slight modification of Oakland's model of total quality management is shown below.

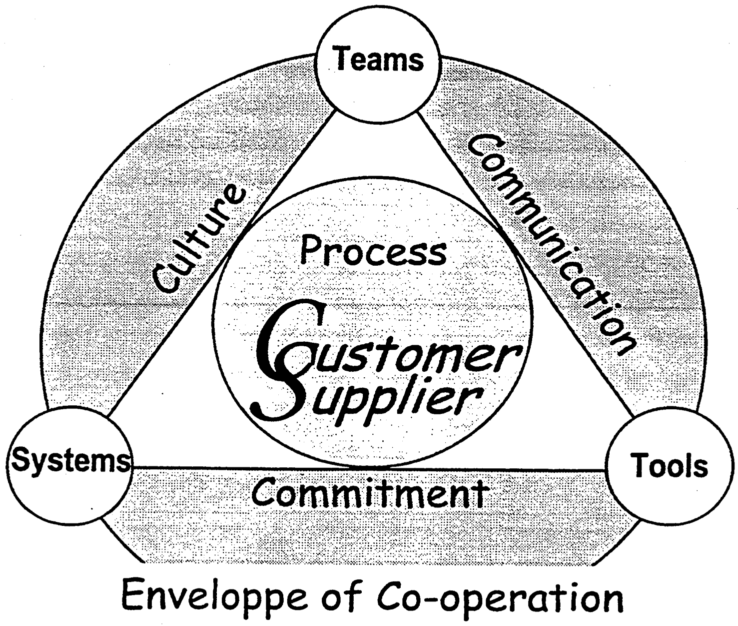

Figure 2: Model of Total Quality Management (After Oakland)

The processes at the centre of Oakland's model link together complex chains of customers and suppliers. The training program at the Ballarat plant emphasised this and in particular continually stressed the importance of appreciating and understanding the concept of the *internal customer*. Deming himself placed a great emphasis upon cooperation, and Caulcutt (1995) argues that the health of a company culture can be measured by the extent of cooperation that exists. Whether it be between departments or between people at different levels, both are indicative of an open culture with a true customer focus, claims Caulcutt (1995).

iv) Other contributing factors:

Two other important factors contributing to the success of the program were the *anticipation* that this was something very special, and significant, and that it would work, as well as an *aura of credibility* that surrounded the instructors. The anticipation factor was not surprising given the well documented success stories from around the world involving such major companies as Toyota, SONY, Motorola, IBM, ABB, General Electric and other subsidiary companies belonging to the Allied Signal group.

Rick Schroeder of Allied Signal has estimated (Bulletin July 16 1996) that for many companies total product defect costs are likely to be in excess of 20% of sales. Given the enormous potential for improvements and savings in many industrial processes it is therefore no surprise that a well thought out, concentrated, rigorous training program will show very substantial early returns, as in fact has been the case. These early successes are an important factor in the continuing successful application of the initial training received. Any researcher will be buoyed by initial success and will most likely be better equipped to continue with the experimental process.

This was particularly true at the Ballarat plant as early in the program groups of shop floor workers indicated strong negative feelings and attitudes. They argued that why should they bother to cooperate as there had been plenty of previous projects of which none had been completed satisfactorily. After initial successes of the projects directly concerned with this work area the personnel are currently far more tolerant and cooperative regarding future project planning.

The credibility factor was an interesting phenomena to observe. The trainee group consisted of people from a relatively small country city comprising new graduates, with no previous work experience, and some company employees who had been with the company for many years. Fly out some instructors from America who are ready to begin within hours of stepping off the plane, who speak with an accent and who quote from personal experience stories and anecdotes from companies such as Toyota, SONY, etc. and you have one quite significant credibility factor (the Red Adairs of the manufacturing world). When these people spoke everybody listened.

From a critical perspective they were not particularly good teachers and neither were their explanations always understandable, nor 100% correct. For example, one instructor claimed that interaction effects could not be modelled using regression techniques. He was unaware that multiplying two variables was equivalent to the interaction between the variables. Another instructor used incorrect terminology when referring to ratios of sums of squares from an ANOVA table.

Program Evaluation

The training program involved three groups of trainees, *Black Belts, Green Belts,* and final year engineering students from the University of Ballarat. The *Black/Green Belt* stratification of the training was inherited from the American parent company. The Black Belts were expected to become the expert problem solvers whilst the Green Belts were expected to fulfil a support role. However, the concept of involving final year engineering students in such a specialised way was an innovation not tried before. The objective was to create a pathway between the University and this particular company in the hope of securing a future flow-on of specifically trained engineering graduates, as well as ongoing statistical support from University staff.

The differences between graduates and non-graduates was quite marked, both in the make up of the groups and in the levels of understanding realised from the training. Four Black Belts were selected comprising 3 engineering graduates straight from university, and a young company employee, without formal tertiary qualifications, but who had been identified as a potential rising star. Eight Green Belts were selected comprising people from various areas throughout the company. Collectively the Green Belts had considerable shop-floor experience between them but minimal tertiary engineering qualifications. It was expected that the Green Belts would find some of the statistical procedures a difficult hurdle to overcome.

Probably the most significant difference between the two groups was that the Black Belts were solely dedicated to their allocated projects whereas the Green Belts were not. The Green Belts were required to fulfil their usual work commitments in addition to working on their projects. This proved to be a very frustrating exercise which was eased somewhat by the support provided by the Project Champion. This was usually in the form of ensuring that suitable computing equipment was made available for these people and negotiating with respective department heads for appropriate time release in order to meet commitments.

Despite the endurance test of long days, and theories regarding effective student concentration spans of 45 minutes or less, I believe the overall program was very successful, and that considerable transfer of knowledge occurred. The success of the program is evidenced in the savings returned to the company in the first year of operation (estimated to be in the vicinity of $800 000). The transfer of knowledge may be evidenced in the project reports submitted by the respective participants. An after-the-event survey is currently being analysed to ascertain participants' self assessment of the value of the training. The success and educational worth of future programs will be measured in part by a special questionnaire designed to measure participants' statistical knowledge before and after similar training programs. Of particular interest will be any differences between graduates and non-graduates that emerge, and future research will focus upon identifying the characteristics of those most likely to receive the greatest benefit from future training, and therefore return maximum benefit to the company.

The challenge ahead

The challenge for those of us who teach statistics looms on several fronts. Here we have an enormously successful program involving relatively high levels of statistical analysis made accessible through computer software. Historically as teachers of statistics we have taught students to test whether or not something is significantly different from something else. Now we need to teach our students to be innovative. George Box (1996), a leading theorist in experimental design believes that statisticians must move out of their "test-oriented mind-sets and take up a critical catalytic role in the process of discovery and development".

The traditional lecture method of instruction is not likely to disappear. It has been seen to be both cost effective and time effective. We must extend the traditional passive role played by the student by actively engaging them in the learning process, and develop programs in which principles and thinking can be taught using applications of immediate interest in a manner allowing the use of familiar learning strategies. As the experimenters of yesterday we need to become the inventors for tomorrow.

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