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The design of education in 'Manufacturing Quality Management' to enable quantifiable industrial improvements by students

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Abstract

Degree apprentices (DAs) undertake an exciting, alternative route to academic qualifications, combining real employment with University study. Here, we discuss their education in 'Quality Improvement' at WMG, focusing on the development of statistical expertise in Year 2 of their programme to procure real improvements in manufacturing and service operations. We show how the preparation for these in Year 1 and the further extension of these in Year 3, interleaved with work-based projects, ensure that DAs can make a significant impact during their apprenticeships. This provides a rapid return on investment for employers, and recognition and faster career progression for DAs..

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Keywords: Education, Apprenticeships, Manufacturing; Engineering; Quality, Process; SPC.

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1. Introduction

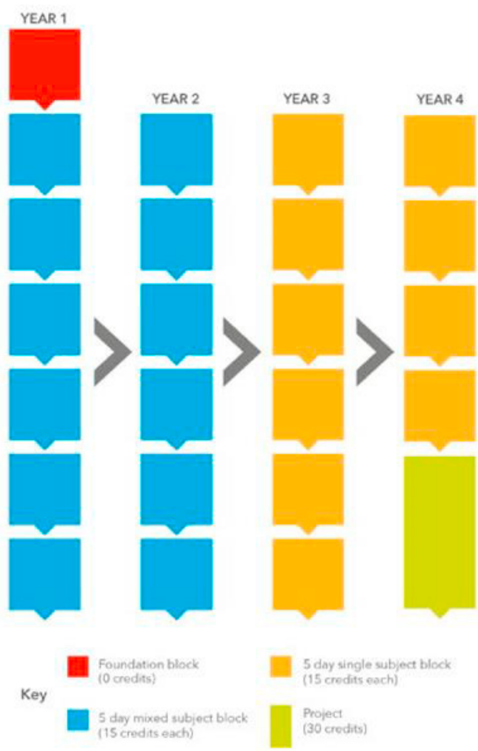
In the UK, Degree Apprenticeships offer an alternative route to gaining a university degree: rather than studying full-time, students combine work with study, obtaining work experience and securing an academic qualification. This scheme is industry led and typically a degree apprentice is employed by a company, paid a salary and undertakes university study one day each week, by block release or a combination of these. The funding for a degree apprenticeship is shared between the government and an employer. Apprenticeships have genuine jobs; thus, apprentices secure the same rights as other employees, including a contract of employment, the minimum wage and at least 20 days paid holiday per year plus statutory holidays.

2. Design of the degree programme

The degree apprentices on the BEng (Hons) Applied Engineering Programme at WMG at the University of Warwick, are employed by industry and study, as part time students on block release, a range of topics/modules as a holistic degree over 4 years. Apprentices learn six themes during Y1 and Y2, namely:

•'Mathematical Techniques',
•'Mechanical Processes',
•'Electrical Principles',
•'Materials Science',
•'Design' and
•'Industrial Management'.

In years 3 & 4 (level 6, Bachelors degree level), the DAs are required to select their specialisation and depending on the specialty, they will take core, week long modules and optional modules aligned to their specialism. A schematic



is provided in Figure 1.

Figure 1: Structure of the "Applied Engineering" Degree Apprenticeship Programme at WMG.

The programme responds to challenges faced by employers by ensure that DAs are equipped with skills that are deemed essential for the next generation of engineers [1, 2]. This paper will focus on the latter. During Y1, apprentices learn the fundamentals of industrial management and structures of organisations; and in Y2 (the basis for this case study) the principles of statistics, and essential tools for statistical improvement in manufacturing and service operations; in particular, 'Statistical Process Control'. In Y3 (or 4 depending on choice), apprentices take a one-week module in 'Advanced Quality Techniques', which comprises concepts such as 'Six Sigma' and strategic elements. DAs take on an extended project (dissertation) addressing a 'real industrial need', typically drawn from their workplace, which currently spans both Y3 and Y4 of the programme. This paper illustrates how the design of curriculum in Quality Improvement can result, by way of demonstrable payback, a true benefit for sponsoring organisation for their investment in the programme.

3. Design of the Quality/Process Improvement Curriculum (in Year 2 and 3/4)

This paper focuses on the subject of 'Quality Improvement' in Y2 and Year 3(or 4) of the of the degree programme, specifically building on the DAs knowledge of Business and Operations, Applied Design and Mathematics. The Y2 'Quality Methods' module provides the DA with practical knowledge of quality improvement techniques that can be utilised during the DAs term as an 'apprentice'. As in Y1, DAs attend the university for six mixed-subject 'blocks', each of which lasts for one week. During each block, DAs attend 4 lectures plus one seminar for each subject; thus receiving 30 hours of teaching contact time for a 15 CAT (Credit Accumulation and Transfer Scheme) module by the end of the academic year. In this section, each block of the year two 'Quality Methods' module will be discussed and will conclude with the Year 3/4 module 'Advanced Quality Techniques'

3.1. Block 1: Quality Management Principles

The focus of this paper is to discuss the importance of providing the DAs with the knowledge and tools that will allow them to make a positive impact at their workplaces; rather than focusing purely on the 'management' and 'strategic' aspects. Introducing the concepts of Quality Management is still important to 'set the scene' and bridge the gap from their Y1 education in Business and Operations. Therefore, the 4 lectures (plus one interactive seminar) introduce topics such as 'the metrics of quality management', 'continuous improvement' and the 'economics/cost of quality'. By concentrating on the elements of process improvement and management, DAs rapidly develop an understanding of how and why every process is equally important to control; furthermore, by learning to recognise non-value adding activities, DAs develop keen insight into how costs of the process can be drastically reduced. Hence, even at this early stage, DAs can begin to appreciate their own workplaces and current role. By identifying the non-value-adding activities, and determining why those activities are being carried out (e.g. over use of inspection), DAs begin to build a foundation of effective process design and (eventual) control (the theories of which will be presented to them from Block 3 onwards).

3.2. Block 2: Fundamentals of Statistics

The second block of lectures in the module is designed to bring the DA up to a common grounding with the tools and techniques of Statistics. A recent study [3] by Andrews and Clark (2017) discuss that the entry requirements into university Engineering programmes (as well as other subjects) have removed the specific requirement for 'A' Level (high school) mathematics, relaxing this to 'A' Level mathematics and/or Science'. The subject matter (as per the Block design) is via 4 lectures and a tutorial to offer the DA the opportunity to practice using Statistical techniques with representative data from industry. The subject matter taught, develops in the DA, an ability to distinguish between a variable and an attribute form of data; this is important as many of the employing organisations use each of these data types in monitoring quality. Depending on what type of data is being considered, the calculations performed to obtain measures of central tendency and dispersion of data differ for each data type. Furthermore, DAs are taught the difference between the concept of a 'universe' and a 'sample' of data; this enables the DA to appreciate how often a sample should be drawn to be able to make appropriate conclusions about the quality profile of the process being investigated (and indeed whether this is representative). This is fundamental for those who seek to improve those processes that are 100% inspection.

The focus of this Block is to introduce the DAs to the Gaussian, or, as it is more commonly known, the 'normal distribution', which provides the basis for the statistical process control (SPC) and improvement techniques which are taught from Block 3 onwards. DAs receive a thorough grounding in the normal distribution, in particular, the characteristics of a normal curve and its relationship to mean and standard deviation. Using this knowledge, they are taught to calculate the percentage of items below a lower specification limit (LSL), above an upper specification limit (USL); or between two values for normal data around a process centre. This allows the DAs to calculate the amount of potential waste and/or rework that may result from poor quality control. This is an essential skill for an engineer; specifically, when the DA performs such calculations using their workplace data, it can result in the realisation of the 'true level' of quality within the process they employ. This is frequently used for the basis of the undergraduate dissertation, which may utilise the techniques employed in this module, as well as their final year module in 'Advanced Quality Techniques' discussed later in the paper.

3.3. Blocks 3&4: Statistical Process Control using Variable Data

Statistical Process Control (SPC) is an integral part of the maintenance and improvement of quality in industry. Implementation of SPC can further improve an organisations ability to meet specification, reduce waste and improve operations [4]. Thus its inclusion (and indeed focus) in a second year module for degree apprentices is of critical importance. A study [5] demonstrated that organisations recognise the need for education and training in SPC techniques to improve organisational quality, but the time resource and ability of the staff responsible was lacking. The study concluded that whilst staff at the varying organisational levels require different levels of depth of knowledge of SPC, there is fundamental need that all staff have an understanding of the benefits of this technique to improve process quality; and that this can develop problem solving skill among staff. As the DA will be able to apply this knowledge at the during the remaining two years of the degree programme, its inclusion can enable the DA to improve the processes that they are themselves responsible for and demonstrate the cost savings for their employer organisations. The design of this education is part informed by this study whereby the specific level of skill and knowledge required by employees of engineering organisations at the 'Engineer' level is specified as being able to:

1. Supervise the SPC process in a company
2. Manage data and audit recorded data and analysis
3. Interpret SPC data and other data/information to determine a diagnosis of fault
4. Identify problems using SPC data and/or charts and make a decision to act accordingly.

In Blocks 3 and 4 of the module, the DA is introduced to the concepts of SPC using variable data (that being 'measured data' as opposed to attribute data [e.g. counted data] which is covered in Block 5). The DA is taught to recognise the categories of variation observed in industrial processes and their sources. DAs then define the concept of the control chart method and are taught to explain the purpose of variable control charts. They are taught how to select the quality characteristics, the rational subgroup and the method of taking samples and calculate the central value, trial control limits and the revised control limits for $\overline{\boldsymbol{X}}$ (average) and 'R' (range) charts. They gain the valuable skill of how to explain what is meant by a process that is 'in control' and the various 'out-of-control' patterns of process outputs. In instances where DAs are in a work environment where sampling may not be possible (for example where volume of output is 'high value' and 'low quantity') they are also taught to determine the difference between individual measurements and (respective) averages with the resultant effect on the control limits and with respect to the agreed specifications. This is particularly valuable for the DA as SPC can be deemed to be a tool that is only appropriate for high volume manufacturing, where indeed, further SPC techniques are available for low volume output, thus applicable for all DAs.

Further techniques that are of relevance for an engineering DA are taught during this phase, such as how to identify and discuss patterns of variation when a process is ‘in control’ and how to distinguish between Type I and Type II errors, Figure 2). This is relevant to DAs as many faults may go undetected due to the errors associated with the method of detection being employed.

	Alarm	No Alarm
In Control	Type I Error	No Error
Out of Control	No Error	Type II Error

Figure 2: Distinguishing between Type I & Type II Errors

During blocks 3 & 4, DAs are specifically taught to discuss Central Limits in relation to specifications and distinguish between the different cases for process capability and tolerance. This gives the DA an appreciation of what their workplace process is 'capable' of producing with respect to the specifications as determined between the (internal or external) customer of the output. DAs are then prepared to calculate the process capability of an engineering case based on their own workplace processes as well as calculation of the capability index (C_{pk}).

3.4. Block 5: Statistical Process Control using Attribute Data

By the end of Block 4, the DAs are conversant with - and have had opportunity to relate the various SPC concepts to data provided from various industries (via lectures) and to apply the concepts to their own workplaces (through the seminars and work based learning). Where the output of processes are not strictly measured in a specific SI unit, it may be more commonplace for an organisation to 'count' the number of non-conforming instances. In such cases, the methodologies learned by the DA in Blocks 3 & 4 would need to be modified to that the binomial distribution is introduced. Therefore in this block the DA is introduced to the limitations of variable control charts and the different types of attribute charts. Given that the specific methodologies are covered in full during Blocks 3 & 4, the detailed process of SPC are not repeated in Block 5, rather modified - for attribute data, in order that the DA can calculate the limits and central lines to produce 'fraction defective' charts for both fixed and variable subgroup sizes as well as 'number defective' charts for when volumes produced as process outputs are very low.

3.5. Block 6: Acceptance Sampling

By the end of Block 5, the DA has been taught the full SPC process and the ways that it can be applied given the varying nature of the outputs (both in terms of volume and the nature of the data). The final block of the module introduces the concept of probability in quality, namely 'Acceptance Sampling'. Engineering organisations employ the use of individual sampling plans to protect against irregular degradation of levels of quality in submitted lots below that considered permissible by the consumer. Shilling and Neubauer (2009) [6] discuss that a good sampling plan will also protect the producer in the sense that lots produced at permissible levels of quality will have a good chance to be accepted by the plan. In no sense, however, is it possible to ''inspect quality into the product.'' In fact, it can be shown that if a producer continues to submit to the consumer product from a process with a constant proportion defective, lot after lot, simple acceptance or rejection of the lots submitted will not change the proportion defective the consumer will eventually receive. The consumer will receive the same proportion defective as was in the original process.

During this final block of the module, the DA identifies the advantages and disadvantages of sampling; the varying types of sampling plans and relative selection factors; criteria for formation of lots; criteria for sampling selection; and decisions regarding rejected lots. They determine the 'Operating Characteristics (OC) Curve' for a single sampling plan and employ the equations needed to graph the OC Curve for a double sampling plan. Rather than being reliant on just calculation, the DA is expected to be able to explain the properties of OC Curves, identify the consumer-producer relationships of risk, the Acceptable Quality Level (AQL), and calculate the probability of accepting a lot with a given proportion defective. In recent times for the automotive industry, this subject matter has fostered much debate during the seminar period. During the seminars for this block, DAs calculate OC curves using industrial data, consider effective sampling plans and consider real life examples where this has led to process failure. Such cases of failure may include examples provided in a commentary by Desai (2017) [7] where he discussed the failure of airbags in VW vehicles that was the result of a breakdown in the sampling processes between carmakers and part suppliers. This allows the DAs to be aware of the current issues within quality inspection for contemporary organisations, appreciate the needs for robust sampling strategies and the need for more transparent relationship between suppliers (both internal and external) and customers (again both internal and external).

3.6. Y3/4 'Advanced Quality Techniques Module'

The year 3/4 module on "Advanced Quality Techniques" builds on the foundation provided in Year 2 where the DA participates in a full one-week programme of study on this subject. During this time, the DA has sessions delivered by specialists in the quality field. Given that that basic quantitative processes are covered in Year 2, this module focusses on building the DAs knowledge of strategic aspects of quality improvement. Topics such as Failure Modes Avoidance (with emphasis on Process, System and Design), World Class Manufacturing, Business Management Systems & Customer Focus and Quality Function Deployment (QFD) are covered in depth. This module is informed by the work of Mazur (1996) [8] who employed the use of QFD to design a holistic Quality Management module. His work using QFD, found that engineering managers require their engineers to have set traits which can be designed into an education programme. Such traits include the need for the engineer to:

- *Have a broad technical quality background*: whereby they can handle statistical and analytical tools as well as complex tasks
- *Be organised*: so that the engineer can feel empowered to enact changes in the workplace, to see/appreciate the 'bigger picture' and know the right questions to ask.
- *Be quality orientated*: whereby the engineer understands what quality is, that they are knowledgeable about customer satisfaction and understand customer needs.
- *Be Innovative*: whereby the engineer can be confident in the use of novel techniques to drive improvements to workplace processes and enhance customer satisfaction.

The design of this module follows this methodology where the DAs produce summative work in groups during the week and are then individually expected to apply the theory to their workplace by generating a quality improvement report. The feedback from the module is consistently high, where in 2019, 92% of participants on the module fed back that the module content was *appropriate for their companies* and 100% of the participants agreed that on the whole, the module was '*good- to –outstanding*'

4. Exemplar Case Studies

During the final year of the degree apprenticeship, the DA is expected to carry out a work based project (equivalent to an undergraduate dissertation) to address an industry need for research and to utilise robust academic research principles. Such projects can vary in nature, all are usually a result of the employer organisation having carried out an identification of an area of strategic importance, thus enabling the DA to take ownership of a project to drive a quality improvement. Where the DA embarks on a project to improve quality, this can result in the immediate improvement of processes and results in a cost saving for the organisation. The extent of the saving and/or improvement will naturally vary according to the differing roles held by the DAs at their employer organisations. Two case studies from 2019 will exemplify how the design of the curriculum enabled the DA to drive improvements at the workplace using their work-based projects (dissertations).

4.1. Case Study 1: Six Sigma Deployment to Improve 'Right First Time' [in an automotive company]

The DA sought to improve the quality rate at the final assembly stage at the largest manufacturing hall of an automotive manufacturer. The DA conducted a literature review on appropriate Six Sigma methodologies. The DA then employed a study to evaluate the tool selection using complexity, cost, customer focus and implementation time as criteria for the time-limited project. Employing the DMAIC approach (Define, Measure, Analyse, Implement and Control), the DA was able to clearly define the nature of the problem to be investigated. Furthermore, these were evaluated against the common faults associated with the particular section of the manufacturing hall resulting in an analysis of the most common faults found and a Pareto analysis performed. By resigning the process layout using knowledge gained from the Year 2 and Year 3/4 module and raising quality alerts earlier (using metrics gained during the project) the DA was able to demonstrate that quality improvements had indeed been realised. The DA analysed the cost of implementation of the project against the outcomes, and when balanced, resulted in ~£10,000 saving for the employer organisation. This project not only highlighted that significant savings can be made, but also that the cost of the activity itself can is far offset from the total savings made by employing the knowledge learned in this curriculum.

4.2. Case Study 2: Application of Quality Techniques to improve the rate of 'Divert Free Vehicles' [in an automotive company].

The DA sought to improve the defect rate at the 'water test' of vehicles using Six Sigma and associated methodologies. Water ingress from a vehicle is a quality failure where this project sought to investigate and determine the cause and to develop a process that would eliminate such faults. Using a Fault Logging and Graphic System (FLAGS), the DA determined the total number of vehicles diverted due to this classification of fault and the impact on divert free vehicles. It was found that the water ingress issue was the largest contributor to costs incurred by the business to rectify a fault when the vehicle is diverted. The MTTR (Mean time to repair) was determined, as was the cost of scrap and summary of the cost to the organisation prepared. This provided a baseline for the DA to determine what improvements could be made to offset the significant costs due to failure. This project also employed the DMAIC methodology presented in the Advanced Quality Techniques module, specifically a detailed cause and effect (Ishikawa) diagram. Subsequently, a Failure Modes and Effects Analysis (FMEA) was performed on the glazing system of the windscreen to determine the ideal geometry. Using CAD (Computer Aided Design), this was optimised to create a 'standard', detailing the height, width and position of the sealant that adheres the windscreen to the vehicle. C_{pk} and C_p was determined (using techniques taught in Year 2) where central lines and quality control limits were determined. The DA was able to quantitatively demonstrate an improvement to the overall quality as well as the process capability of the operation. During the course of the project, the DA produced a new 'work board' (Figure 3) which the manufacturing hall now use to monitor quality in this specific area.

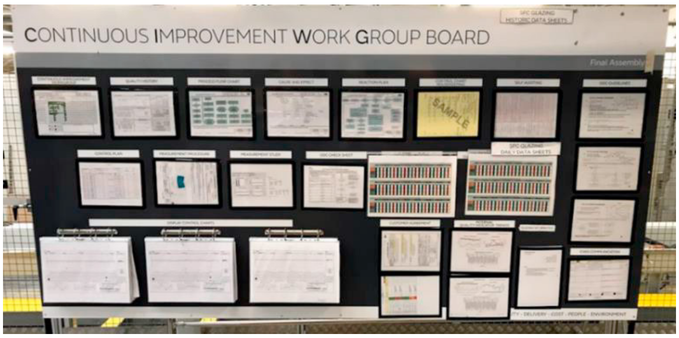


Figure 3: Application of the Quality Improvement tools by the DA at the workplace.

This board utilises run charts from Statistical Process Control, defect rates and overall quality, all of which was a culmination and application of the curriculum presented in this paper. The DA was able to solve 72% of the issues arising from this particular quality failure as well as saving an annual ~£26,500 per year in costs due to quality failure.

5. Conclusion

This paper has discussed how quality improvement curricula for degree apprentices can be designed to suit industry needs. This paper advocates the teaching of fundamental statistical systems and root quality improvement techniques that can be implemented at a position/workstation typically manned by a DA in the time that they are serving their apprenticeship. Typically the employer organisation will engage the degree apprentice in a final year project that addresses a real life industrial problem. In this case, the problems that the degree apprentice seeks to solve are directly related to their current role in their organisation. As such, a (long term) strategic project is unlikely to result in any significant improvement in the short term. By teaching fundamental principles of statistics and toolsets of statistical process/quality improvement, the DA can quantify the current processes and subsequently target areas for improvement. Once the new process has been implemented, the DA is able to compare the new state with the previous state and quantify the benefits. This gives the employer organisation an immediate benefit gained from engaging in the apprenticeship and the DA themselves are recognised for their contribution to their workplace and advance in their career.

6. Acknowledgements

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