Mathematical Skills in the Workplace

Final Report to the Science, Technology and Mathematics Council

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Foreword by the Steering Group

This Project looked at the requirements for mathematical skills and understanding in the workplace by undertaking a number of case studies in seven sectors of the economy.

A key finding of this study is that 'mathematical literacy' is displacing basic numeracy as the minimum mathematical competency required in a large and growing number of jobs. Mathematical literacy is the term we have used to describe the application of a range of mathematical concepts integrated with a detailed understanding of the particular workplace context. There is a need to distinguish between numeracy, mathematics skills and mathematical literacy. (see endnote).

The findings from the case studies are suggesting that at all levels of the workforce:-

- Mathematical literacy can contribute to business success in an increasingly competitive and technological based world-wide economy.
- There is an inter-dependency of mathematical literacy and the use of IT in the workplace but that this is not always appreciated.
- The findings have implications for adopting a more systematic approach to business success in terms of appreciating the critical part played by employee's mathematical skills and knowledge.

In discussion with, for example, SSDA, SSCs, Government Departments, the Devolved Administrations and other stakeholders ST+MC will:

a) Explore the avenues and vehicles by which the recommendations below may best be carried forward.

b) Identify lines of enquiry in this field/area which would benefit from further study.

Recommendation 1 – Raising Visibility and Awareness of the Importance of Mathematical Literacy in the Workplace

The focus should be:

- The nature of mathematical literacy – that it is anchored in real data, in the context of a particular workplace.
- That maths used in the workplace has economic benefits in the market-place.
- That mathematics may be present quite implicitly in jobs and tasks, which are not obviously mathematical.
- Many employees, regardless of their level of employment, are required to use mathematical literacy.
- That IT and mathematical skills are interdependent.

- Employers are best placed to be, and must be, actively involved in developing mathematical literacy to meet the needs of their sector/workplace.

Recommendation 2 – Generate models for training/Professional Development to promote mathematical literacy

The focus should be:

- Exploring ways to help employers identify the precise role of mathematical literacy in their work practices, including how this literacy is acquired.

- Exploring how mathematical literacy can be developed in ways specific to a sector.

- Developing models of new forms of training for all employees which reflect mathematical literacy that is integrated with IT competence in addition to procedural skills.

Recommendation 3 – Identify/further define core concepts which provide the basis of mathematical literacy – this has implications for pre-employment education and training

The focus should be:

- To further investigate core aspects of mathematical literacy and how these are acquired.

- To investigate the development of training programmes which will be effective in the workplace by achieving a balance between physical experience and software packages, e.g. CAD/CAM.

- To identify pre-employment mathematical learning experiences to support the development and enhancement of mathematical literacy.

- Consider the extent to which the existing education provisions and qualifications provide the right basis for developing mathematical literacy.

Recommendation 4 – Communications with employers should recognise that employers need to understand the mathematical literacy they can expect from national qualifications

The focus should be:

- Carry out further investigations in order to understand more precisely what is useful information for employers.

- Determine how educators could communicate this information more effectively to employers, including ways of enabling closer links between schools, FE, HE and employers.

Endnote:

Aspects of mathematics that the study highlights from different sectors as being of significance in mathematical literacy include:

- Integrated mathematics and IT skills
- An ability to create a formula (using a spreadsheet if necessary)
- Calculating and estimating (quickly and mentally)
- Proportional reasoning
- Calculating and understanding percentages correctly
- Multi-step problem solving
- A sense of complex modelling, including understanding thresholds and constraints
- Use of extrapolation
- Recognising anomalous effects and erroneous answers when monitoring systems
- An ability to perform paper and pencil calculations and metal calculations as well as calculating correctly with a calculator
- Communicating mathematics to other users and interpreting the mathematics of other users
- An ability to cope with the unexpected

Mathematical Skills in the Workplace

This report is divided into three parts: Part 1, an Executive Summary; Part 2, research findings on a sector by sector basis; Part 3, case studies of individual companies.

Part 1: General Conclusions and Executive Summary

General Conclusions

The overall conclusions of this project are that mathematical skills in the workplace are changing, with increasing numbers of people involved in mathematics-related work, and with such work involving increasingly sophisticated mathematical activities. In agreement with other recent studies, we conclude that the country needs to rethink and look to upgrade mathematics provision for young people and to ensure that people have access to additional provision over their lifetimes.

In the changing context of business practice, alongside new requirements following from the deployment of IT, the project has identified the central importance of what is termed *mathematical literacy*. The concept of mathematical literacy provides a useful device for describing current practices and needs; identifying skills gaps in the workforce; and predicting skills shortages in the future. Mathematical literacy is described below in terms of its component skills and its strong inter-relationship with IT, and is illustrated by reference to examples from case studies across the different sectors studied.

Executive Summary

1. Introduction

The report presents the findings of research undertaken between May 2001 and March 2002 into current requirements for mathematical skills in the workplace. The study was commissioned from the Institute of Education (University of London) by the Science, Technology and Mathematics Council. A Steering Group oversaw the project, and included representatives of ST+MC, Regional Development Agencies (RDAs), DfES, and QCA.

Seven sectors were identified as the focus of the research, in consultation with representatives from the RDAs and on the basis of a preliminary briefing paper from the research team. All the sectors were identified as high priority by RDAs, and all English RDAs have at least one of their high priority sectors included in the final list.

The sectors selected were:

- Electronic Engineering and Optoelectronics
- Financial Services
- Food Processing
- Health Care
- Packaging
- Pharmaceuticals

- Tourism

This report is based on intensive case studies of three companies or organisations within each sector, supported by previous and related work (including previous research on workplace mathematics carried out by members of the project team) and validation seminars with a wider range of sector representatives.

2. Objectives of the project

As agreed by the Steering Group during the early phases of the project, these were:

a) To identify the mathematical qualifications and skills demanded by employers across the chosen sectors.

b) To determine the mathematical skills and competencies required by employers in these sectors.

c) To investigate the skills and competencies that employees felt were needed for the job, and what they currently possessed

d) To make recommendations about what needs to be done to address future requirements for mathematical skills in workplaces.

e) To produce a list of those skills and competencies needed in different sectors

3. Methodology

A list of companies was drawn up following consultation with the RDAs, from which a sample was selected by the project team to represent as far as possible the spread of sectors and geographical locations. Where the RDAs had made contact with the companies and encouraged them to participate in the project, the progress of the research was smooth. When this was not the case, some problems were experienced in obtaining access to companies. In all, a total of 22 case studies were undertaken. Each case study comprised an initial 30 minute semi-structured telephone interview with a key person in the company (following a set of agreed questions). Following this interview, a site visit was arranged which was again structured according to sets of questions, but with flexibility allowed to follow up interesting avenues for further investigation. (See Appendix for the two survey instruments.) The final versions of the case studies were sent to each company to check for accuracy, and a variety of methods was used to obtain wider sectoral comment and validation.

We should emphasise that our case studies do not represent a random sample, either for each sector or for businesses as a whole, and this probably does have a significant effect on some aspects of our findings. In particular (see section 8), we did not observe any companies with critical skills gaps for mathematics. This is to be expected in that only thriving, successful companies or organisations are likely to open themselves up to the scrutiny of a research team.

4. The demand for mathematical skills in the workplace

Not all case studies in all sectors demonstrated the same set of needs: the annex to this summary lists some particular requirements that were expressed or identified in the different sectors. Nonetheless, recurrent themes are evident. From the business point of view, mathematical skills are always deployed towards certain goals.

We have distinguished, for reporting purposes, five interrelated goals within which these skills can be grouped: improving efficiency, dealing with constant change and innovation, informing improvement, remaining competitive, and maintaining operations. All these goals require mathematical skills and competencies. We have also identified type of work, size of company and position in the business cycle as factors likely to affect companies' particular mathematical needs.

In terms of types of work, the case studies cover production, design, marketing, administration, accounting and management, or combinations of these. In relation to size, we have noted that larger companies appear to exhibit more specialisation, fragmentation and outsourcing and have more need for effective formal communication systems. Finally, in terms of the business cycle, we have identified different mathematical needs depending on whether the company is just starting up, expanding/merging or has reached a position of equilibrium where practices are largely routine.

Goal 1: The drive for efficiency

In the 'manufacturing' sectors considered (Food Processing and Electronic/ Optoelectronics), the companies surveyed were hugely concerned with improving efficiency. We gathered many examples of *complex modelling* of the relationships between variables, whereby production data were gathered and manipulated to provide an evidence base for action planning and decision making. Although company practices varied (with the larger companies proceeding more 'scientifically'), a common feature was the expectation that *all employees*, regardless of level, were involved in the process of increasing productivity or producing efficiency gains, and therefore all employees needed relevant mathematical and IT competencies. Nor was this general trend confined to manufacturing: for example, in health care management a key unit of resource is the 'Finished Care Episode' (FCE), encompassing the total cost of care from the moment a patient is referred till the moment they are discharged. Understanding and monitoring of trends in FCEs is central to the ongoing drive for greater efficiency in the National Health Service.

Goal 2: The culture of constant change and innovation

It is characteristic of many sectors that companies need to change and innovate constantly. For example, the Financial Services sector aims to provide a constant supply of 'new' financial products to customers (mortgages, investments, etc). *Fast-changing practices generate a demand for mathematical skills.* One example is the ability to 'create formulae', almost inevitably involving use of spreadsheet software (see the Financial Services section in the main report for a detailed discussion). Where industries change constantly (new products, new activities, new regulations), not all the required operations can be built into centralised IT systems, automated production systems and operating procedures. Those operations which become 'core' will, after a while, be incorporated into the main systems, and thus become routinised, but the regularity and speed of change involves many employees in new and additional tasks which involve mathematical work.

Goal 3: Informing improvement

A significant number of companies across the sectors (though not all), were investing in *operating methodologies concerned with quality, continuous improvement, and reducing waste.* (The methodologies observed in the case studies included Overall Equipment Efficiency, Key Performance Indicators, Total Preventative Maintenance (TPM), and Six Sigma.) These changes go beyond ‘conventional’ efficiency improvements of the type mentioned above, and reflect sector-wide changes, towards a requirement for higher absolute levels of quality, smaller margins of error and tolerances, reduction of wastage and quality procedures which can be easily audited. All of these require mathematical competencies for interpretation.

For example, in Packaging, quality control was a key issue in each of the three case studies: put simply, many of the production processes in use would not work at all without rigorous quality procedures.

Approaches to quality differ by company type and position in the business cycle. At the research/development stage there is a strong reliance on team work, cross checking and multi-stage checks. In an established manufacturing process a company may be looking toward implementing more rigorous quality methodologies (e.g., Six Sigma) whilst having to balance the benefits of higher quality against the costs of implementation.

Goal 4: Remaining competitive in changing markets

Some companies spoke about being under pressure to remain competitive in markets that are becoming larger and often more international, *which requires constant monitoring of rapidly changing data*. An example observed in Packaging (Case Study 1) was a company that operates by constantly bidding for new contracts: the type of contract used has changed hugely in the last five years, from simple one-offs delivered to UK-based clients, to multi-stepped, pan-European contracts for multinational clients. In larger tourist attractions and in most hotels, mathematical literacy has also become more vital to competitive success because of the growth of international markets, tied into IT-based operations. For example, a large urban hotel (Tourism Case Study 2) is constantly in competition with numerous other hotels in the city, adjusting its rates dynamically (thanks to sophisticated computer software) in response to many variables (time of year, occupancy level, type of customer, etc). At the same time, the hotel customer base is also becoming increasingly multi-national.

Goal 5: Maintaining operations

In the midst of so much change and innovation, it is important to keep in mind the often mundane operations that keep companies going. For example, to maintain factory machinery in good order there is a need for both routine and emergency maintenance, where the *skills demanded are multi-faceted, including recognising when action must be taken, often on the basis of mathematical information.*

An example of routine maintenance is the replacement of worn machine parts (see Food Processing Case Study 1), which requires precision at all points of the process, conversion between units and interpreting 3D situations from 2D diagrams.

In production-oriented companies (e.g. Pharmaceuticals Case Study 1), there is a need continuously to keep track of stock with limited shelf life, which requires systematic data-entry and monitoring.

5. The interrelationship of IT and mathematical skills and practices

All the sectors exhibit the ubiquitous use of Information Technology.* This has *changed the nature of the mathematical skills required, while not reducing the need for mathematics.* On the contrary, in many cases, a competitive and IT-dependent environment means that many employees are using mathematics skills that their predecessors, or they themselves in the past, did not require. For example, at several of the case study companies, PCs are being installed on production lines so that machine operators can enter quality control data directly into centralised databases, whereas in the past this information was manually recorded and processed elsewhere by administrative or management staff.

The way that IT was used by companies varied along a spectrum from total automation of a process, to use for monitoring and routinised operations, through to use as a 'modelling' tool for the design and redesign of products and processes. As an example of the first type, two of our case studies in Health Care (numbers 2 and 3) could not function at all without their computerised systems. The use of IT for monitoring (including efficiency drives) means that employees increasingly need to appreciate the output (and sometimes the input) of computer software and also the nature of the underlying model used by the software. Financial Services also provides an example of this second type of use: although financial products are always calculated for new customers using 'easy to use' software, a sales agent must be able not only to manipulate values, but also to explain to the customer what the software is doing. Finally, the essence of many of the mathematical skills observed is what we term *complex modelling*, and this too is bound up with IT use. It involves understanding the significance of, and the relationships between, numerical and categorical variables in IT-based models, and appreciating the assumptions underlying the choice of variables and relations, as well as interpreting output to identify problems and trends.

Automation by IT tends to be more extensive in larger, better-resourced companies. In the case of a small bakery (Food Processing Case Study 3), spreadsheet software is used only in a semi-automated way, using the tabulation and data storage of the spreadsheet to support employees' implicit judgements, mental notes and mental calculations. More automation might be possible in such cases, but this would offer rather little advantage while a company's development is being constrained by other quite different factors.

In general, IT transforms workplace practices and the skills required. For example, the existence of CAD/CAM software means that more complex products can be visualised, producing a need for new IT/visualisation skills. This does not mean that IT adoption is necessarily unproblematic. For example, some companies are questioning whether the lack of physical experience of creating prototypes, and its

* It has become common in recent years to replace the term IT with ICT — Information and Communications Technology — due to the growing significance of the Internet. However, electronic communication did not feature significantly in any of the case study companies, so we have intentionally kept with the term IT.

contribution to the all-round skill of the employee, means that opportunities to develop more efficient, better-designed products are lost.

It is important to emphasise that a lack of understanding of how IT and mathematical skills are interdependent can lead to ineffective education and training practices. Effective use of IT for mathematical ends is not achieved by simply adding decontextualised mathematical skills to decontextualised IT ones. Over-simplistic assumptions about IT training can mean that only fragmented procedural skills and techniques are taught (in a number of case studies, we found that training in the use of software packages, mostly Excel, was largely procedural). We suggest that this issue needs to be addressed in the development of future training provision.

6. The fusion of mathematical skills and workplace contexts

It is not always easy for companies, or individuals within them, to identify the precise role of mathematical skills in their work practices. The way in which the mathematics is bound up with factors specific to workplaces and tasks can make it hard to identify the components of skills and knowledge that are regarded as ‘all part of the job’. The use of mathematical skills is more obvious in some sectors than others. For example, in Pharmaceuticals, a frequently-cited need was an understanding of basic proportionality, which is required for the preparation of chemical solutions to specified concentrations. This clearly involves a grasp of basic and generalised mathematics skills; but here too, it is essential that people ‘understand what they are doing’: that is, what calculations mean *in the context of the work*. There is no guarantee that someone who was simply expert with proportionality could work unproblematically with concentrations.

Some of the skills we observed can appear to be quite basic, such as how to calculate and estimate (often quickly and mentally), and having a ‘feel’ for numbers, percentages and proportions. But these are never required in isolation. ‘Simple’ mathematics skills have to be deployed analytically in sophisticated ways. They have always to be operationalised with real data and with an appreciation of what these data mean. One point, which recurred frequently in the case studies, was the need for workers to recognise immediately that a particular piece of mathematical information was implausible and possibly just wrong. This kind of judgement requires a combined appreciation of mathematics and the context and content of the work practice. It is important that employers and education and training providers recognise this fundamental fact. Employers should not expect young people fresh out of formal education to operate like experienced workers, and educators should recognise the importance of giving students experience with multi-step, data-dependent operations.

7. Mathematical literacy

The mathematical skills and competencies that we have identified as recurring in the sectors studied comprise what we characterise as *mathematical literacy.* Mathematical literacy is framed by the work situation and practice, and, in many cases, by the use of IT tools. We summarise mathematical literacy as involving:

- analytical, flexible, fast and often multi-step calculation and estimation in the context of the work (with and without the use of IT tools)

- complex modelling (of variables, relationships, thresholds and constraints),

- interpretation of, and transformations between, different representations of numerical data (graphical and symbolic)
- systematic and precise data-entry techniques and monitoring
- extrapolating trends and monitoring models across different types of work
- concise clear communication of judgements
- recognising anomalous effects and erroneous answers.

Alongside the modelling side of mathematical literacy, there is also the need to know how to calculate and estimate and to have a feel for numbers, percentages and proportions. Mathematical literacy is, however, much more than a set of simple and disconnected skills; and it goes well beyond a command of number or basic numeracy. It is anchored in real data (often in the form of data output from spreadsheet models), and set in the local and global context of the work. It involves an appreciation of the thresholds and constraints of a model (such as the limitations on factory output, the costs of machinery, or throughput of production lines), flexibility in understanding different representations of the model (the columns of a spreadsheet; charts or graphs, or, less commonly, symbolic forms), and being able to modify the model to improve the simulation of workplace practices and outcomes. *Though it is often hidden, we maintain that mathematical literacy is of increasing importance*.

We noted a trend in the case studies for workers at *all levels* of organisations being required to possess an appropriate level of mathematical literacy. This is partly because of the need to delegate to individuals responsibility for monitoring work-place activity in relation to business goals, but also the need to communicate mathematically-expressed decisions and judgements to others; for example, ‘vertically’ within a company to justify a plan or prediction or to explain a trend; ‘outwards’ to customers or clients; and ‘horizontally’ within teams.

As discussed earlier, mathematical literacy is being deployed in environments where IT is ubiquitous. A common theme across the case studies was concern over the possible fate of traditional, pen-and-paper and mental mathematical skills. Many companies specifically require employees to be able to operate without IT — whether for checking for anomalies (e.g. Financial Services) or to perform calculations that IT cannot handle (e.g. AutoCAD in Electronic Engineering/Optoelectronics). Also, there was some evidence that younger people currently entering workplaces will not have the same opportunities to master important mental calculation and visualisation skills as in the past (cf. Health Care Case Study 3).

8. Mathematical requirements across the workforce

Here we discuss some commonalities noted across different companies and sectors and point to possible gaps and shortages in skills.

Common trends

The mathematics skills required — or rather, in our terms, the mathematical literacy demanded — depend not simply on the individual jobs that people are doing at a particular time, but also on how organisations deploy staff, and on general labour market trends. In some companies, there is a strong delineation in the skills required for particular positions, whereas in others there is evidence of much crossover. It is common in some sectors (for example, Financial Services and Tourism) for employees to be recruited with the expectation that they will move between roles as their career develops. We observed that highly-qualified people often do ‘technician jobs’ and relatively basic-qualified people often do highly complex jobs, not necessarily in narrowly-defined areas (see the findings for Electronics/ Optoelectronics in Part 2). It is thus misleading to think of skills needs in terms of a highly segmented labour force, where skills requirements are fixed, and tied to specific and unchanging roles. It is also (correspondingly) wrong to assume that, because skills are not being demanded for particular jobs at a given time, they are not useful or necessary to the people holding those jobs.

Overall, the following common trends were noted:

- Team-based working is widespread, and in some sectors is becoming more common because of its importance in improving processes;

- Because of the pressure of business goals and the introduction of IT, the need for mathematical skills is being progressively extended throughout the workforce. Different personnel in the employment hierarchy need to deploy mathematical literacy in different ways; for example, data collection and ‘first level’ analysis (i.e. where problems are obvious) are becoming increasingly a responsibility of shop floor workers, thus allowing line managers to undertake more analysis of a strategic nature;

- There is a growing need to communicate information effectively, based on mathematical data and inferences, and involving colleagues, customers and external inspectors;

- There is a need for *hybrid* skills (for example, good technical and analytic knowledge combined with ability to communicate analytical information; or good people management combined with financial/budgeting skills; see the example in Packaging Case Study 1). This has implications for the content and structure of both education and training.

Skills gaps and shortages

The sample of companies and organisations surveyed in this study cannot be regarded as fully representative of the sectors involved: as noted above, it is inevitable that companies who are willing to invite in a research team will be biased towards the successful end of business, and hence we should not expect to see ‘critical’ shortages in the case study data. Nonetheless, the following gaps and shortages in skills were identified:

- There was evidence of a shortage in the area of the hybrid skills mentioned above, for example mathematical skills combined with communication or people skills;

- In some companies, the expectation that all employees, regardless of level, should be able to use mathematical literacy at work has made training in these skills for all employees a major issue; such skills gaps were being actively addressed in the majority of the case studies;

- Some companies are tending towards obtaining necessary skills by recruiting directly into higher-level positions (rather than allowing people to progress in a 'time-served' manner); this does have the danger of creating a 'gap' at the management level of people with a sound appreciation of the grassroots context of the work;

- Occasionally, a company experiences an unanticipated mathematical skills gap, which must be rapidly dealt with (see Electronics/Optoelectronics Case Study 3, example of negative numbers).

9. The mathematics required by employers

Senior managers in the case study companies were generally very aware of the potential value and importance of mathematics skills for their workforce, although they varied in how formally they had analysed these and whether they referred to them explicitly in recruitment. It was common to set different criteria for professional (i.e. higher education qualified) or non-professional staff:

- *Professional*: few companies specified a mathematical qualification as such, instead inferring sufficient mathematical ability from degree (or other degree-level, such as HND) attainment in the professional subject. A-level mathematics was not given as a specific requirement: this almost certainly reflects the fact that very few people now enter the job market direct from A-level.

  - *Non-professional*: it was common to ask for GCSE Mathematics (grade C minimum), and to require satisfactory performance on a company-administered basic numeracy or quantitative reasoning test (often a commercial product: SHL (Saville & Holdsworth) are the market leaders in such tests).

In addition, some employers are rethinking their recruitment policies and on-the-job training schemes as a result of a perceived need for higher levels of mathematical competence and the changing mathematical requirements of the workplace, as described earlier. The way the commercial environment has been transformed, in part by IT (see section 5 above) has meant that companies either need to hire people who are already in possession of skills or need to develop these skills quite quickly through training, whereas in the past they might have relied on developing employees' skills over time within the organisation (see section 8 above).

A point of concern raised by some employers (notably in the Food Processing and Electronic/Optoelectronics sectors) was the difficulty of using school mathematics qualifications, and also in some cases degree qualifications, as clear and/or reliable indicators of competency in the recruitment process. The problem was described in one company in terms of the 16+ qualifications framework (GCSE, NVQ, etc) being too complex and too variable for employers to understand and to follow. They are responding to this by administering entry tests, and being more selective about the degrees which they accept from job applicants. It is also the case that job applicants may have taken their qualifications 20 or 30 years in the past, and so these do not attest to current skills. This is a particular issue for companies who need to recruit large numbers of shop-floor workers in a short period of time, for example 'high tech' start-up companies who move rapidly from R&D to manufacturing, or food processing companies with seasonal product lines.

This complex situation manifests itself in a number of ways, including the use of entry testing; some employers' simplified perceptions of 'falling standards' in school examinations; and recruitment of higher-level qualified candidates than has been the case previously. It must be stressed that the range of views and practices is diverse and there is often little consensus within one company, let alone across companies. However, it should also be noted that these issues are affecting the way in which qualifications are used and specified by employers, particularly at the recruitment stage.

In principle, it is desirable that employers should have a better understanding of the mathematics experienced in schools and colleges, but they are unlikely to do so if frequent and rapid changes in qualification structure and content continue to occur. It is evident in the case study data that the information some employers would like is not being satisfactorily communicated to them by the education sector. These employers do have a notion of 'the standard' of mathematics that they are looking for: understanding this more exactly, and determining how educators could better communicate information about it, requires further investigation.

10. Implications for education and training

The requirements of mathematical literacy have implications for recruitment and training, including training for 'shop floor' workers who have in the past been expected to have little or no formal mathematical or IT qualifications or for employees with formal mathematical skills who need to appreciate how they are contextualised in the workplace. A discussion of ways to develop mathematical literacy may be a fruitful avenue to explore. This will require enhancing awareness of the nature of mathematical literacy and how it can be developed in ways specific to different commercial and industrial sectors.

At the same time, for many companies the notions of 'time-served' and 'experienced' remain important. Discussions which refer to 'a skill' as though it were a discretely-defined object, risk implying that you can be trained directly in it, bypassing the long and messy experiential process. The evidence from the case studies is that this thinking is flawed. For example, separating 'IT training' from the context of workplace practice is problematic, in the same way the mathematics present implicitly in jobs and tasks which are not obviously mathematical, cannot be 'lifted out' for training purposes. This suggests that new forms of training for adult workers should reflect mathematical literacy, rather than decontextualised skills.

Annex to Executive Summary: Mathematics requirements for each sector

Set out below (using 'mathematical skills' terminology) are specific areas of skill observed in use in the case study workplaces. *The lists are not intended to be exhaustive* but rather to demonstrate the range and variability of mathematical skills actually deployed across the seven sectors that were studied. This arrangement of skills provides an alternative perspective on the mathematical demands of the workplace, compared to the perspective made evident by a focus on business demands in Section 4 above. It also provides evidence for the pervasive nature of mathematical activity in the workplace.

Electronic Engineering and Optoelectronics

Measuring, calculating and using quantities accurately (in the design and manufacture of products), including converting between units of measurement

Moving between 2-D and 3-D representations and objects

Statistics of normally-distributed data (to monitor quality of products)

Geometry and trigonometry (in the design of complex parts, mainly but not exclusively via CAD/CAM packages)

Communication of data and mathematical information (within teams, for example)

Modelling (of the interaction of different parts of products, and of product behaviour)

Financial Services

Multi-stage calculations including percentages

Ability to understand relationships (including indirect and multi-step) between variables

Ability to read, interpret and transform data from charts and spreadsheets

Ability to create formulae

Confidence in identifying, appreciating and using concepts of risk and probability

Ability to use approximations, estimates and formal probabilities to model likely events

Food Processing

The ability to read, interpret, transform and communicate data, in the form of charts, graphs and numbers (in monitoring and improving operational efficiency of a production line)

Ability to understand relationships (including indirect and multi-step) between variables (in stock control)

Measuring, calculating and using information accurately (in the maintenance of machinery)

Health Care

Quick (often mental) calculations on basis of charging values in a model

Communication of data (charts, numbers)

Mental calculation and (3-D) visualisation skills

Statistics of normal distributions (for establishing ‘normal ranges’ for new pieces of analytical equipment)

2 and 3-dimensional representations of data (mostly in the form of special charts specific to the practice, not general graphical representations)

Manual analytical tests requiring some simple calculations with substituting values into algebraic formulae

Packaging

Measurement (statistical sampling)

Statistics of normally-distributed data

Complex modelling of numerical and categorical information, including linear and non-linear relationships (to cost a job)

Communication of data (to improve operational efficiencies)

Pharmaceuticals

Statistics of normally-distributed data

Data trending (correlation between chemical samples, and in the time variation of individual samples)

Understanding and working with quantities and proportions (concentration and dilution of solutions)

Understanding exponentials and powers

Communicating mathematical and statistical information

Tourism

Calculating and monitoring quantifiable variables (of a hotel's performance)

Modelling (designing and maintaining models for room rates)

Identifying trends statistically

Appreciating and using (informal) concepts of risk and probability

Design and costing of capital investments

Rapid mental calculation and approximation

Part 2: Summary of findings in each sector

Electronic Engineering and Optoelectronics

Introduction

Three companies were surveyed, all doing electronic engineering with a specialisation in optoelectronics:

- Case Study 1: Relatively new start-up company, in receipt of venture capital to develop a novel fibre optic-based technology for telecommunications and scientific research.
- Case Study 2: Medium-sized, well-established development and manufacturing company catering primarily to the defence sector.
- Case Study 3: Component manufacturing division of an established high-tech company, selling products to the telecommunications sector.

Mathematical qualifications and skills demanded

This sector is heavily dependent on the mathematical skills and competencies of its employees and few people would be employed without a minimum GCSE grade ‘C’ (or equivalent). CS3 recruits across all age ranges so GCSE is not a good general requirement; the company administers numeracy tests and new recruits are assigned to numerate roles (or not) on the basis of scores in the tests.

The type of business also influences the type and level of qualifications demanded so that individual company profiles vary dramatically. The range of qualifications demanded extends across PhDs (usually in physics/engineering rather than mathematics) to GCSE grade ‘C’ – or what employers view as its equivalent. For companies doing research and development, the skills requirements are generally higher: for example, CS1 is currently employing people with degrees for its technician posts (such skills demands will fall as manufacturing processes develop and mature).

It is not the case that those with the highest qualifications are in the highest positions within the company. In CS1 and CS2, company activity is normally based around ‘projects’ with tasks distributed across teams of employees; so the ability of individuals to work in teams, consisting of a range of levels of mathematical expertise, is also necessary. CS3, a manufacturing site, has a more traditional-looking profile for manufacturing industry, although even here changes are becoming evident.

A-level does not appear to operate as a significant entry-level qualification in that people either enter from GCSE level onto an apprenticeship route (often involving HNC/HND study), or people enter as graduates with A levels in the background. Both GCSE and A-level qualifications are used as the basis for other qualifications and do not appear to be used as an end in themselves.

This sector requires high levels of mathematical skills for the majority of posts but, more importantly, these skills often need to be combined with other skills, for example, communication and IT skills. Mathematical skills ‘on their own’ would not be sufficient and the need for ‘hybrid skills’ was clear.

A shift to higher-level qualifications – the need for adaptability

In CS1 and CS2, although for different reasons, the companies are moving towards recruiting people with mathematical qualifications at a higher level than they would either have expected or previously needed. In CS1, this is partially driven by the need for particular skills to get the company established and partially related to a lack of confidence in employee's capabilities with mathematics that can be demonstrated with lower qualifications. In CS2, the shift was associated with the need for greater flexibility of thinking required in the 'knowledge economy' and wanting to recruit people directly into roles as well as training and developing people on from apprenticeships.

CS3 had shifted in recent years from an R&D phase, similar to that of CS1, where the emphasis was on employing people with potential to adapt to the work, rather than specific skills, towards a more usual profile found in the engineering manufacturing sector. As is typical of the sector, the company supports technicians to upgrade to degree level via part-time study.

Our observations were that highly-qualified people may be doing 'technician jobs' and relatively basic-qualified people may be doing highly complex jobs. There is not a straightforward relationship between the competencies required to do a job and the skills formally acquired by the person doing that job.

Uncertainties about qualifications

In tandem with the shift to requiring higher mathematics qualifications/training was a feeling of growing uncertainty by employers about using school qualifications as 'standards' by which to measure job applicants' mathematical skills. Thus, in CS2 the need for entry tests was described as 'needing to establish a standard' and to maintain a sense of uniformity over time. Recruiters in CS1 and CS2 were not aware of the 'tier' system of GCSE mathematics qualifications. Their minimum mathematics requirements are strictly adhered to and the companies would not expect to make exceptions to these.

The perception that standards in the mathematical competency of young people are falling was expressed at managerial, supervisory and 'shop floor' levels within CS2. Likewise, CS1 had found degree-level people lacking in both mathematical and hybrid mathematical/communication skills and this had resulted in the shift to employing only graduates with certain degree backgrounds into key technician roles.

The training manager in CS3 held the view that it was more the complexity of school qualifications that was at stake than the standard:

> …too many qualifications, too many grades. In the old days it was simple for employers to understand, O levels or A levels, and the exam titles were understandable as well. Now there are so many qualification titles, to keep up to date, to understand their relevance, is a nightmare.
>
> Every generation says that school exams have got easier, so I don't know the answer to that. But, for any of the GCSE, GNVQ, etc qualifications, I'd far rather see grades of 'excellent, good, pass' and then I'm not interested in the rest.

In a similar vein to that expressed in CS2, this was also the justification for entry tests:

> Whilst we're happy with degree, HND, etc qualifications, we can't rely on school leaving qualifications, or people who have returned to education to re-qualify. It's too hard [to make sense of], too much work involved.

At the same time, within CS3, a view was expressed that GCSE was at a higher level than that required by the majority of shop-floor workers:

> The level of mathematics covered in GCSE is higher than most of what we use here, so I don't think it's a problem of curriculum, but motivation or attention… I don't see a lack of ability, some operators can work out permutations and combinations in their heads, but simple things like averaging and negative numbers, they couldn't put together.

This possibly indicates confusion about 'levels' and/or content coverage, or is an issue around the use of mathematical ideas in workplace contexts, where the ideas may be simple or complex but are transformed in the working practice into something differently 'simple' or 'complex'.

Overall, employers seem less concerned about 'preferred' qualifications than getting a better handle on what the different qualifications mean, and what holders of these qualifications are competent to do. Greater awareness is required, on behalf of employers, of the form, content and level of mathematical work undertaken within the education sector. Some of the information of use to employers may not be communicated very well by the education sector at the present time. Employers did refer to 'the standard' of mathematics that they are looking for: further work is required on what employers mean by this, and the consequences for educators to communicate this information.

Additionally, some reflection may be required on the part of employers regarding how the demands of the workplace have changed, and how this places different demands on workers and their skills and qualifications.

Ensuring quality control

Quality control was a key issue in each of the three case studies. Regardless of the place of the company in the business cycle (start-up, development, manufacturing) or type of product, the nature of the work requires the highest quality standards and not simply for reasons of competitiveness or profitability. Put simply, many of the products of these companies would not work without rigorous quality procedures. However, the approaches taken to quality control did differ. In CS1, procedures were still at the development stage; in CS2 a strong reliance on team-work, cross checking and multi-stage checks underpinned quality assurance; whilst in CS3 the manufacturing process is established, using 'statistical process control' (SPC) and the company is looking toward implementing further quality methodologies — Six Sigma in this case.

The key to implementing a 'total quality' methodology like Six Sigma is ensuring that operators from the lowest level up become more responsible for their own work and this requires operators becoming competent in using SPC methods of data collection and analysis. Although SPC is already used, responsibility for acting upon the information would be devolved down, resulting in a need for operators to 'upskill':

> I think operators will need a better appreciation of the charts, analysing for themselves and making changes themselves, to put the process back under control quickly, rather than waiting for someone else to come along. So it's a case of training people to have the confidence to make changes for themselves, and to know the reasons and consequences of the change. The key thing is to devolve knowledge to the operators so they can keep processes under control minute to minute.

At the same time, there was a strong view that this devolution of knowledge would not require development of higher mathematical skills and was more of a culture shift about taking on responsibility:

> I don't think it necessarily requires more mathematical skills. How much operators are going to need to know that we haven't worked out yet. I mean, how much does a rally driver need to know about a car's engine to drive the car?
>
> The issue for us is not maths skills, but about culture, which is all to do with communication.

As discussed in the Executive Summary, the perception that 'maths skills are not really involved' is open to question.

The trend of devolution of responsibility is one theme which finds echoes across many of the case studies in this project and not only within this particular sector (see also Food Processing).

Relations between mathematics and domain knowledge

In CS1 and CS2 the need for mathematical skills to be combined with the engineering knowledge involved in each job was paramount. This aspect was less evident in CS3, although the need for operators to deal with negative numbers, and what they represented, had recently been an issue.

In CS1, for example, they are developing specifications and sets of test procedures to move from making prototypes to full-scale manufacturing. The main scientific problem is wavelength tolerance and knowledge of the science on this topic is essential to development of the specifications. Thus, operators check fibre characteristics at many stages in the production of the product. This checking involved the use of multiple forms of data collection and analysis, including working with formulae and use of spreadsheets. If something was 'going wrong' an operator would need to resolve it, evaluate the problem and change parameters to get things back on track; plus, noting down all of these to feedback to the designer of the test procedures. Although this development of the testing procedures was viewed as requiring a person with degree-level maths skills, once the procedures were in place it was expected that the monitoring and evaluation role would be occupied by a person at technician level (HNC/HND qualified with some element of specific technical knowledge in optics).

It was difficult for the majority of technical people interviewed to step out from the 'it's all part of an engineer's job' kind of viewpoint when describing their work. However, there was strong consensus that experience and time-served-ness were very important; that you needed to grow into the job and keep yourself updated. Also important was the need for a broad-based understanding of 'what you're interfacing with' (that is the context and scientific field), not just focus on 'your job'.

Measurement

At the root of all activity in all case studies were processes of measurement. Measurements are taken manually, using instruments (often digital technologies) or produced in an automated way by machines. Some quite basic issues around people's capabilities to take, understand and appreciate the role, power and use of measurements were evident.

The need to perform measurements when other devices break down is imperative. As an example, from CS2:

> An engineering draughts-person needed to measure a length. The person had to do the calculations by hand as the computer-based design programme was unable to cope with the complexity of the length measurement. Although the mathematics involved in the calculation was fairly basic trigonometry the draughts-person was not confident that a newcomer (regardless of qualification) would be able to do it. He was clear that you needed a good idea of the answer beforehand; that you shouldn't be reliant on the technology (AutoCAD); and that one needed to be able to anticipate answers and recognise problems and be able to perform when the AutoCAD couldn't.

IT skills needs

In all three case studies the need for competency with computers and other technology was widespread at all levels of employment. IT is embedded in the culture and working practices of these companies regardless of the differences in size and position in the business life-cycle. Software used included CAD/CAM packages, Word/Excel for reporting and simple statistical analysis, statistical software and specialist in-house programs.

In CS1 the ability of employees to handle IT and move between IT and non-IT aspects of a given task was taken for granted.

In CS2 staff turnover is very low and employees remain with the company for much of their working life, therefore the company invests in training and skills development with people developing new skills, particularly in relation to IT, over time and as their roles demand. There did not appear to be any resistance or difficulties with older, experienced staff in gaining new skills but these experienced staff were more confident about their knowledge of how to do things without computers and they often used non-IT methods to check on their work. There was concern amongst experienced staff that newer recruits would not have the mathematical skills to do this kind of checking, and thus would be too reliant on the IT methods.

In CS3 the use of SPC processes is reliant on people's competency with IT and the ability to act on the information generated by the technology was becoming increasingly important.

Financial Services (Retail)

Introduction

The sector of the financial services industry covered by these case studies involves retail sales made directly to individuals and households (i.e. the sector most widely represented across the English regions).

- Case Study 1: Medium-sized, rapidly growing building society, with associated insurance services.
- Case Study 2: Small long-established building society.
- Case study 3: Medium-sized financial group selling pensions, unit trusts, etc. (Curtailed study, telephone interview only)

Validation of the findings was carried out through an email survey with the cooperation of the Financial Services National Training Organisation.

Mathematical qualifications demanded

GCSE Mathematics grade C is a minimum requirement for employment and is used as a basic screening device at entry. (There is no stipulation about GCSE tier.) Except for a few positions where qualified accountants are required, there are no other formal requirements, and the industry has a strong tradition of internal promotion. However, many staff obtain banking and other qualifications, with a mathematical component, as part of normal career progression. Whereas 20 years ago, many staff entered at 16 after O level, entry at 18 after A level or equivalent is now increasingly the norm. However, formal minimum requirements remain phrased in terms of GCSEs and their equivalents. There have been various graduate entry schemes within the sector as a whole over the years, operated by one or other company, but these are not the norm. (This contrasts with multi-national/ investment banking which typically employs a small core team of 'rocket scientists' as well.)

Standard of qualifications: This was not raised as an issue by any of the case study interviewees, although lack of initiative and problem solving skills were mentioned as a problem by a number of respondents.

Ongoing training and development

Highly specific and targeted training takes place in relation to new financial products and changes in IT systems. Otherwise, for building societies, the main area in which in-house training takes place is in preparation for the granting of mandates, which allow individuals to sign off loans at various levels. General financial services (including call-centre based) emphasise customer contact training. There is a certain amount of training in the use of software packages (mostly Excel) but this is largely procedural rather than specifically related to company procedures and requirements, or to underlying mathematical and analytical competencies. In addition, many employees study in their own time for banking and finance qualifications (e.g., financial planning certificates): this is a standard practice and expectation in the sector, and employers may pay for books and materials.

Key mathematical skills required

In spite of the difference in size between the case study companies, there was a strong similarity in the mathematical skills required. Only very few jobs required *formal* mathematics at above intermediate level: conversely, around 30–40% of workers, at any given time, are felt to use mathematics at a level which goes well above that required to obtain the entry-level minimum of a GCSE C. Given the tradition, in this part of the financial services sector, of promotion from within, this implies a demand for this level of expertise from more than 40% of employees.

Key mathematical skills required of a large number of employees are:

Multi-stage calculations including percentages

In the last few years there has been a major shift away from doing a lot of calculations on hand-held calculators to having everything on a central computer system, with the formula for a particular product/operation ready-entered. Nonetheless, there is a perceived need for staff to be able to do the calculations (on a calculator) themselves. This may be as part of an explanation to customers (during a sales talk). For example, one interviewee noted that building society branch staff, who present mortgages (and make underwriting decisions), have to be able to present approximate monthly payment figures to customers under different assumptions:

> I wouldn't expect them to have to go on to the system for that. They have to know what proportion they can take of various things that count as part of salary… work out monthly payments on an interest only mortgage... these are basic calculations and I expect them to be able to do that without the aid of a computer.

People who struggle with these calculations, and rely 'too much' on the system, are also, in this interviewee's opinion, those who tend to be 'too black and white' in the way they apply policies and rules.

Ability to understand relationships (including indirect/multi-step) between variables

This is related to the ability to spot errors *and* to explain and correct them. A point which recurred frequently was the need for staff to recognise immediately that a particular numerical figure was at best highly implausible and probably just wrong. Allied to this is the ability to work out why an error has occurred: although in practice it was reported that staff who can do the former can also do the latter. The most frequent reason for such errors is an inputting error somewhere *or* a change in an Excel formula which is an unintended consequence of a deliberate change somewhere else.

The ability to error-spot relies partly on familiarity with numbers ('3 and a half times that *can't* be anything like that') but also on understanding the underlying relationships between variables in the system.

Even within a highly routinised, IT-based system, it is necessary for staff to understand how different payments, and entries within the system, relate to each other: and also for staff to be able to employ this knowledge to spotting, explaining and correcting errors. These general abilities can be applied, however, only in conjunction with a great deal of company-specific knowledge (about the system and about the society's procedures and products). For example, to deal with insurance debits and credits, the employee has to use two screens: one showing a customer's monthly premium and one showing what has actually been debited. Customers may be on monthly, or three-monthly, or six-monthly direct debit arrangements: so before putting through a manual debit or credit, both these pieces of information have to be used. It is also necessary to know and take account of the fact that, when an insurance policy is activated and backdated, or when it is cancelled, with back-dated repayments, some of the debiting/crediting will be automatically generated by the computer, and only some must be done manually. Otherwise you get the sort of situation described by one interviewee, when 'a customer… had cancelled an insurance on account and when I looked at his transactions there was a debit of £998 and a refund of £998 and a refund of £707. So I said to the girl concerned, "I think this customer is very pleased with you!"'

This ability is also critical in determining whether staff are able to take higher-level policy-setting decisions accurately. As one interviewee pointed out, you don't increase your company's income multiplier (i.e. multiple of your income clients can borrow) when interest rates are on the rise! Junior staff with this capacity are reasonably easy to spot: 'The good ones ask questions all the time.'

Ability to read, interpret and transform data from charts and spreadsheets

Staff in financial services (as in most other industries) frequently review activity over a time period. This almost invariably requires them to take the reports which the system generates automatically (i.e. is programmed to generate through a single command), and then analyse them further — often by entering outcome data into a further spreadsheet they have designed themselves, and which they use to manipulate and transform the data, and sometimes through visual scanning and interpretation.

Ability to create formulae

Such formulae are almost inevitably created in relation to spreadsheet use. This may be for non-routine monitoring, but even more often, it is to carry out operations not built into the system. Central systems tend to be standardised/bought in. Moreover, they reflect core activities at a given time. In an industry which is changing constantly (new products, new activities, new regulations) this means that some operations will not be built into the system. Those which become 'core' will, after a while, be incorporated into the system by IT staff: but the frequency with which interviewees created and used additional spreadsheets which they had created themselves (and shared with subordinate staff) was striking.

Confidence in identifying, appreciating and using concepts of risk and probability

In most cases, what is needed is a *general* grasp of probability and risk, and a confidence in thinking probabilistically, again in a general way; not the capacity to formalise probabilities or calculate the exact consequences of different risk levels. However, this general ability is fundamental, and interviewees noted that its presence or absence often differentiates staff who will be promoted/successful from those who will not. For example, in underwriting (deciding whether to give a mortgage and on what terms) there are definite rules which lay down a customer's mortgage eligibility and amount they can be offered. (Companies review and change these regularly, but they provide the parameters for calculations and offers.)

Most decisions to offer (or refuse) a mortgage are made at branch level, where certain staff will have been given a mandate to make offers up to a certain level. Some societies use a formal credit scoring system (in which would-be borrowers get points for a list of questions/indicators) while others have a set of rules, including the multiplier of income that can be lent as standard. 'Good' underwriters will be those who can judge when to bend the rules and lend outside policy safely: poorer underwriters may be those who go outside policy in a misguided way, but are more likely to be rigid appliers of the policy rules – something which more senior members of staff perceive to be associated with a lack of mathematical confidence. One of our informants described a situation where:

> We had a trainee solicitor who was earning £25,000 and wanted to borrow £100,000. That was outside our standard multiplier at the time which was 3 and a half times income – on that you couldn't get there, and he was being turned down. But in fact he had a sizeable deposit, with which his parents had helped him, and he was with one of the biggest firms in town, which we know well, so we knew he'd be on £35,000 within a year or so. That should definitely have been approved straight away — we wouldn't even have coded it as a high risk for regular monitoring.

In summary, any underwriter has to be able to work with figures, and also have confidence in the decisions they make: but the best underwriters are those who are not unduly tied to rigid rules, and who can combine local knowledge with judgement and appraisal of risk.

Equally, staff in central operations will decide which loans, on which criteria, should be flagged as bearing certain levels of risk, reviewed regularly, and the results fed into future general policy. This process, as interviewees insist, relies on detailed local knowledge, experience etc., but it is also the case that many staff simply do not have and do not develop the capacity to operate in this probabilistic way. And the ability to do so is also related to the more general ability to see and think in terms of relationships between (abstract) variables.

New product launches tend to be decided on the basis of probabilistic calculations of this rather informal and approximate kind, based on experience and some general 'best case/ worst case' scenarios, rather than on formal modelling. This reflects the need for speed and a quick response to market conditions and competitors' activities. The process nonetheless assumes a high level of confidence in the application of intermediate mathematical skills and probabilistic thinking to complex scenarios.

Ability to use approximations, estimates and formal probabilities to model likely events

This set of skills is rather different from the others, in that it implies something more than intermediate level mathematics, and is also (at present) a relatively rare requirement. It is associated with formal modelling of risk which, within the retail part of the financial services industry, seems to be quite rare. (The small building society in our sample argued that its scale of operations made this level of formal analysis inappropriate.) However, demand for these skills is likely to grow in the future because of the potential use of such techniques in helping companies to *quantify* the likely results of having operated a different, a more rigid, or a less rigid system of ‘credit scoring’ (whereby different indicators are used to generate a ‘score’ for an individual’s mortgage application and allocate it to a low, medium or high risk category) or to examine precisely which types of business generate not just volume, but different rates of return (on all costs). Until recently, this degree of formal modelling was almost impossible because the data were simply not available. Now, the near-universal use of centralised IT-based systems means large data sets are available readily, although they still tend to need considerable preparatory work before formal analysis can start.

Food Processing

Introduction

Four companies were surveyed, covering food production on large and small scales, and also food marketing:

- Case Study 1: Large, frozen food production facility.
- Case Study 2: Small, produce-marketing and distribution agency.
- Case Study 3: Small bakery.
- Case Study 4: Large, baking and ready-meals production facility.

Validation of the findings was carried out through an email survey in collaboration with one of the participating Regional Development Agencies.

Mathematical qualifications and skills demanded

Minimum mathematical qualifications required varied significantly across the case studies and were in part dependent on the size of the company but also related to the role into which people were recruited. In CS1 a matrix structure of skills and competencies – directly related to roles within the company – was used, therefore minimum qualifications were dependent on job a person was being recruited into. At the lowest levels no mathematical qualifications were expected but potential employees still had to pass literacy and numeracy tests to be taken on. In CS2, with only 6 staff, the overlaps between roles and tasks often meant that not everyone needed mathematical competency. At the same time, and based on the Director's previous experience at a large company, there was a strong belief in the need for a grade 'B' GCSE as a minimum and that vocationally-related qualifications for 16-18 year olds (BTEC, GNVQ) would not be seriously considered. In CS3 no minimum was stipulated and much mathematical work was embedded within spreadsheet technology which people were trained to use on the job. In CS4 no minimum was stipulated for workers on the shop-floor; beyond this, time-served technicians and graduates were expected to have attained well in mathematics as part of their professional studies. This variability reflects a highly diverse sector: thus, in some other companies, which commented on our results for validation purposes, vocational qualifications *are* used (though not usually as a proxy for mathematical and other general skills).

Standards of qualifications

Responses to the validation questionnaire (sent out by email to an RDA-coordinated network) indicated that while some companies are not at all clear about the standard of GCSE, others are confident that they understand it.

Recruitment, especially for operator staff in food production, was often across the age range, which makes a stipulation of a school-leaving qualification unworkable. Thus, in CS1 recruitment entry testing has been implemented to remove the need to request a specific qualification.

Ongoing training & development

All four case studies engage in active on-the-job and additional training. CS1 in particular is concerned to address the perceived culture of the food processing industry as one of low skills and low pay. CS1 invests heavily in employee development in terms of both time and money, using the NVQ structure to promote and monitor progress. CS4 also uses the NVQ structure and aims to get 30% of shop-floor workers to Level 2 (in a food-related course) by the end of 2002, rolling out to the whole shop-floor within 5 years. The purpose here was mainly to improve people's on the job performance. CS2 and CS3 were primarily concerned about highly specific on-the-job support to develop any mathematical or IT skills needed.

Future expectations of qualifications and skills

There is a general 'upskilling' movement evident in the sector, whereby shop-floor workers are provided with general or job-specific training whilst working for the company. In both CS1 and CS4, shop-floor operators, who are likely to have left school without any qualifications, are increasingly needing to work with numerical data represented in both numerical and graphical forms, and to take decisions based on this information. Taking people on without formal qualifications and training them up was viewed as a more viable strategy than recruiting people directly in with more qualifications for these relatively low-level jobs.

The drive for efficiency and quality assurance is pushing the larger companies of CS1 and CS4 to involve shop-floor workers in performance improvements, a trend which is set to continue for the foreseeable future. Empowering workers at this level means that workers at technician levels are freed-up to take a more strategic outlook and to action-plan over longer terms. In CS1 this move has lead to recruitment at the 'craft level' being discontinued, with HND being viewed as having the minimum requirement for strategic work.

IT skills needs

IT use, in the form of spreadsheets, databases and accounting software, was widespread. In CS1, line managers are responsible for entering data and the production of visual presentations of data to inform production line target setting. Technicians use this data and additional information to construct cases for technical improvements; this group of workers is moving to the use of an Access database. In CS2, Excel was viewed as essential, and in CS3 Excel was vital to the running of the operation. However, interviewees in both these (small) companies emphasised that decontextualised IT skills were of little use: IT enhanced and could be integrated with other skills, but was useless without them. (As one of them expressed it, 'I don't want the FE college sending yet more kids who've been on IT courses: IT's just a small part of it. Why can't they send someone who can ice cakes for a change?')

Increasingly, IT is an integrated aspect of the workplace and the need to work with information, and to present it to different audiences and for different purposes, indicates that IT skills may also become more important even at the lower skills levels. A good number (but not all) of the companies studied, or involved in validation, felt that responsibility for data collection and data manipulation was being devolved down the management hierarchy, with implications for skill needs.

The drive for efficiency

In the two large production companies (CS1 and CS4) there was an overriding concern with improving efficiency and this drive was made evident in the gathering and manipulation of data to provide an evidence base for action planning and guiding decision making (both by senior management and shop-floor line managers). In the small bakery (CS3), the concern was more limited, nevertheless the need to operate tightly and efficiently (using spreadsheets to monitor stock levels continuously) was crucial. In the larger companies, one feature common to the three cases was the expectation that all employees, regardless of level, are involved in the focus on improving quality and efficiency, and one consequence of this is the need for all employees to be able to interpret information, not just to blindly record it for interpretation by managers. In CS1 this process of involving all levels of employees was well established, whereas in CS4 this process was just beginning.

This drive does rely on all employees being able to work with and interpret data, a situation which companies need to address through ongoing training programmes for many staff. Where previously, well-qualified managers have solely dealt with data and abstract information, increasingly all workers are required to engage. This necessitates a shift in the ways data is represented: for example, graphs were viewed as more easily understandable than figures in percentages. Abstract information must be conveyed in 'people friendly' ways, using concrete examples (e.g., 'gross margins are down by so many percent this month' will be translated to 'this product used to sell for £1.48 and now it sells for £1.46; it still costs us £1 to make, so we're making 2p less per packet, and think about how many packets we make here').

Informing improvement — the ability to read, interpret and transform data

Within the larger companies, the efficiency drive is based around improving operational efficiencies. Although differing approaches were being taken to this, the collecting of information on which to base improvement decisions and plans was central. In CS4, a strict hierarchy of roles means that data are manipulated and transformed by managers and fed back to production line operators; in CS1, operators are involved in the generation, manipulation and transformation of data. For example in CS1:

> All line workers collect data, primarily through filling in charts of hourly totals and running totals through their section of the line. These data, together with other data collected from the line as a whole, are entered by a line leader onto a 'downtime chart' (e.g. hourly operational efficiency, % waste, and stoppage time etc.) which forms the basis of much further data manipulation and processing. Downtime data are entered onto a PC database so that it is accessible to managers for their work and the line leader will use the data, for example, to generate graphics of operational efficiency. Much of the data gathered is represented in graphical form, 'they have a graph for everything' , and these are displayed alongside the production line machinery. Each morning, a line meeting takes place around the displays, discussing the data and ideas for improvement, the actions to be taken and new targets to be set. Clearly, the ability to discuss and understand information presented in graphical form, as well as other forms such as percentages, is necessary at all levels.

At higher levels, technicians will analyse the 'downtime' data over longer periods and results over a number of lines may be collated and lessons for improvement subsequently generated.

A number of companies in the sector base their efficiency drive around continuous improvement methods of production (e.g. Overall Equipment Effectiveness; Six Sigma). There is no one-to-one relationship between use of such methods, and whether managers believe that continuous improvement requires them to develop employees' mathematical skills explicitly: some felt strongly that one implied the other, others did not. Where there *is* agreement is on the need for employees to understand what they are doing and what information means.

Attention to detail — understanding relationships

Increasing use of spreadsheet software such as Excel has enabled the smaller companies to streamline and monitor aspects of their operation. The use of spreadsheets requires that employees can make sense of what the spreadsheet is doing and understand that information in one place on a worksheet may be linked to other parts of the worksheet. An ability to spot erroneous results, when they occur, and trace the source of the error, is needed. This process was described in CS3 as the need for 'attention to detail'.

> One of the things we're struggling with at the moment is updating the cost per unit of the products ... You've got the transfer of information from recipes, a lot of which are historic and written in imperial units, going into a metric formula, because a lot of the raw ingredients — not all though, it's still a mix — are in metric units. So you've got to watch carefully, for example a can of golden syrup is sold as '4 pounds', but the spreadsheet has a metric volume. So there are little things, not necessarily mathematical to the eye, which they've got to be watching all the time.
>
> Once the spreadsheet is in place it should be working itself out. The staff have got to be looking for anomalies. We have found that suddenly the price of a cake based on the raw ingredients will go from £1 to £1.50 in a six month period, and so I've had to say, go back and look because there's obviously a problem there, the raw materials haven't increased by 50%. And when they go back they'll find that often a raw ingredient has been entered in imperial instead of metric or vice versa, or one of the cooks has changed the recipe and that information hasn't been fed through. They might have changed from 4 ounces of ground almonds to 5 or 6. Although there's a mathematical problem there, it's a matter of attention to detail in the workings.

Ongoing maintenance — calculating and using information accurately

Larger companies are often heavily automated (virtually 100% in CS1, 50% in CS4) and so maintenance of machinery is an integral part of operations. In CS1, line-assigned technicians are responsible for routine and emergency maintenance and the skills employed are multi-faceted, including recognising when action must be taken, often on the basis of mathematical information. One example of routine maintenance in a food processing company is the replacement of worn parts:

Technicians often preferred to make replacement parts themselves rather than send an order out. Diagrams, with or without dimensions, may be available of the part to be replaced; alternatively they will remove the part and take all the measurements required directly from the piece. Calculations on ‘how much metal to lose’, although straightforward arithmetic, would also involve thinking and working in 3-D. Lathes/milling machines are either set manually or programmed and conversions between imperial and metric units of measurement are commonly needed. Precision at all points of the process are important, ensuring that parts are produced accurately and to avoid delays in the line being out of action.

Health Care

Introduction

Three Health Care organisations were surveyed:

- Case Study 1: Health Care management ‘Primary Care Group’.
- Case Study 2: Large pathology laboratory in an NHS Trust.
- Case Study 3: Cancer therapy unit in an NHS Trust.

CS1 is rather distinct from CS2 and CS3, so we present the key findings separately.

Mathematical qualifications (CS1)

Few mathematics qualifications are explicitly required. Yet a drift to degree entry was noted with mathematics as an element of the degree to some extent. There are two routes to promotion to middle-grade NHS management: directly with general management background or through promotion from, say, nursing sister or senior physiotherapist.

Mathematical skills (CS1)

There are different needs but ultimately managers must interweave data analysis with knowledge of the meaning of data: there is a need to see trends in clinical and management data, make predictions, spot outliers, spot unusual patterns. Also managers are expected to be able to manage finances in terms of understanding (though not producing) balance sheets and how they are made up; understanding debit/credit (is overspend significant?, is action needed?); capital/ revenue; costs and deferred costs.

There is a need to be able to interpret data (‘What the figures are saying to you’), in terms of financial aspects and the quality of care. Also a need to understand the implications and validity of research and have the ability to challenge results and raise questions.

The following skills were required, all of which relate to highly contextualised data:

a) quick calculations on basis of changing values in a model.
b) understanding and monitoring of trends in FCEs (costs of a finished care episode), percentages of targets achieved, and flexibility in response to new government targets.
c) communication of data in charts, and understanding the representations in terms of NHS.
d) financial management.

There is a need for hybrid skills: mathematical plus other (for example, operational and people management). In particular there is a need for analysts who can monitor data and appreciate their meaning in terms of NHS practice and government targets.

A stratified workforce (CS2/3)

There is a clear division between professional (state-registered) staff and low-qualified assistants. (This is not surprising, perhaps, considering the life-critical nature of the clinical work being undertaken.) CS2 has a sizable minority of assistants, but their role is clearly demarcated not to involve making judgments.

CS3 has no assistants currently for the technical work (it does have for patient care work), but this is going to change in the future. A national recruitment shortage of 20% for therapy radiographers means there is a pressing need to employ assistants to do limited aspects of the technical work, and do on-the-job training as a first step to professional status (followed by degree etc.).

Mathematical qualifications and skills (CS2/3)

Because of the stratified workforce, assistants are not required to have any mathematical qualification. Professionals are only required to have GCSE Mathematics; though they must do extensive technical studies (in CS2, right through into masters-level training, and similar things are planned for radiography in CS3), which presumably have mathematical elements to them, at least in the sense of keeping mathematics active in people’s minds.

Computerisation and automation (CS2/3)

Both case studies feature workplaces that are highly computerised and automated, and becoming increasingly so. A common theme was the need to review the fate of traditional, pen-and-paper mathematical skills. Despite the fact that computers have made the carrying out of calculations redundant, there was evidence in both case studies of important mental calculation and visualisation skills that, in the past, have been learnt through doing repetitive, routine calculations, and which young people entering the profession do not appear to have the same opportunities to master as in the past. (It is not possible to say more about this within the scope of the present research, but it is certainly an issue worthy of further investigation.)

Packaging

Introduction

The three companies surveyed were as follows:

- Case Study 1: UK factory of a multinational company, making printed cartons to contract ('jobber printer').
- Case Study 2: UK factory of a multinational company in plastic packaging.
- Case Study 3: Small, independent 'contract packer'.

The first two companies are similar to each other in company structure and operating culture, both being sites within very large multinational companies, though the physical nature of the packaging materials are different. The third company was selected as a deliberate contrast, being much smaller and offering specialist manufacturing and contract packing services (ie. it takes in raw materials and packaging, blends a product and fills it into individual containers, ready for retail sale).

A validation meeting was held for this sector, organised by the Institute of Packaging at their headquarters. This involved two people from the Institute of Education team, Institute of Packaging staff, and six representatives from major packaging firms. The findings of the first two case studies were reported, and received favourable feedback. The findings presented below are based on those originally presented at the meeting, revised in light of the attendees' comments.

A rapidly changing industrial sector

The packaging industry has changed hugely in the last ten years, with an enormous amount of IT-based technology having been introduced, and a marketplace which is much more competitive, with profit margins very much leaner than they used to be, and clients demanding higher quality and more complex contractual arrangements:

> If you look back 10 years, the variability in our products would have been huge. And the customers didn't care so much, because their supply chain was not that sophisticated, and waste was not very visible; the drive for profit and cost reduction was nothing like what it is now. (Case Study 2)

Mathematical qualifications and skills

The packaging industry has become greatly concerned with process control and improvement, and this has impacted directly on the mathematical skills of the workforce. In CS2, there have been big changes between now and 10 years ago: previously unskilled shop-floor operatives now need at least minimal numeracy (which is measured by a compulsory numeracy entry test) and the skill levels required will increase in the next few years. This is being backed up by having a Learn Direct centre on site, to support employees' self-study, and various training initiatives set up with a local FE college, including work on mathematics and IT. At management levels, the feeling at CS2 was that time-served, promoted employees are going to struggle to develop the formal mathematical skills now required for the job: the trend is to look for management recruits with a degree background.

CS3 is somewhat different to the other two, in that it is a small company with more limited resources to develop its workforce. Still, the management there expressed concern about the numeracy (and literacy) skills of shop-floor employees, and said that it would like to improve these in the future. At senior levels, the emphasis is still very much on people having to become experienced with the specialist work of the company (many of the senior staff have 20 or more years experience), with specific formal qualifications being less important.

In terms of skills shortages at technical or management levels, no major problems were reported in any of the companies, though there were a few gaps in specific technical and manufacturing areas. More significantly, in CS1, there was a significant gap in multiple skills, that is, managers who could be equally strong in technical, administrative and 'people' skills:

> You get somebody from the shop floor with technical skills but will struggle with the admin side, and management people who struggle with the technical; that's the only shortage area — a lack of all-rounders. (Case Study 1)

This was confirmed as a general point of concern at the validation meeting, where it was also mentioned that there was difficulty in replacing staff with technical experience built up over many years. At the same meeting, it was also suggested that there has been too much emphasis placed on degree qualifications and maybe more qualifications specific to the packaging industry are needed.

Process control and process improvement

Both CS1 and CS2 have computerised systems to collect and analyse data about their manufacturing processes. These are abstract models of the process which, increasingly, *all* employees are expected to understand to some level. The style of working where employees are told what to do by managers, without understanding the reasons why, is no longer tenable. Process improvement targets are set year-on-year, again expressed in the same abstract models.

CS3 is different, in that it must do process control and improvement in the context of completing many small, possibly one-off, contracts. This requires dealing with abstract efficiencies in the manufacturing process alongside the optimising of the many specific, technical details of each contract.

Managing and communicating information

The concern with models of processes has made managers' roles much more concerned with managing and communicating information. This is especially challenging at line manager (team leader) level because those managers are often time-served shop-floor employees, with relatively few formal qualifications:

> We're data-driven much of the time, and it is clearly our strategy to push a data-driven approach right down through the organisation. Now, team leaders have to come and present to me a lot of analytical data about what happened in their shift. 5 years ago it didn't happen. Now, they've got to understand it to make things happen. I have a programme every few months of spending half

> an hour with every team leader, and at that meeting they have to give me loads of information. Increasingly, we're making the selection process for team leaders very rigorous, lots of tests, a 2-day residential assessment course, looking at leadership, communication, analytical problem solving, technical skills. Year on year, it's becoming more technically-oriented. (Case Study 2)

See also the examples concerning the Works Manager in the CS1 description.

Complex modelling

The increasing emphasis on process control and improvement, and (in CS1) the need to deal with more complex contractual arrangements with customers, can be described as a need for managers to deal with the complex modelling of numerical and categorical data. Some aspects of this, evident in the case study data, are:

- understanding the significance of numerical and categorical variables in models.
- appreciating the meaning of numerical data in terms of the workplace practice.
- appreciating the meaning of variables, and relationships between them, in terms of performance indicators.
- a need to be transparent and simple.
- managing variables and predicting trends.
- understand that variables are related and how these relationships determine outputs.
- appreciating assumptions in the choice of variables.
- understanding linear and non-linear relationships.
- being able to prioritise tasks in the face of so much information.

Many aspects of the categorical data are related to the complexities of materials in packaging: sourcing, variable quality, dealing with wastage (which varies over time, e.g. because of changing government regulations).

Pharmaceuticals

Introduction

Three companies were surveyed:

- Case Study 1: Small manufacturing plant, in a period of major change as it develops rigorous quality control processes in line with new international standards.
- Case Study 2: Large R&D laboratory, testing the performance of prototype drug products prior to manufacturing.
- Case Study 3: A technology 'spin off' company, currently in R&D phase.

Mathematical qualifications and skills demanded

The three case studies represent different sub-sectors of the Pharmaceuticals industry, and also all are currently experiencing different operating conditions.

CS1 is in manufacturing, where generally the need is to establish robust operating procedures that will then remain unchanged for a long time. However, the company is in the middle of a radical change to its procedures, and the skills required of its employees are shifting radically. One pressing issue is that experienced shop-floor employees have a need to acquire significant IT skills that did not exist previously.

CS2 is part of a large, mature R&D operation, where the variable nature of the work generally demands flexibility from the workforce. The majority of employees are at least graduate-trained, though it was noted that 'basic' skills problems (see below) were being found at both technician and graduate levels. Intermediate maths skills are demanded for the majority of technicians: 'Everything we do is about data, so everything is tabulated and everything will have graphs drawn, and statistical analysis done; most data will in some way be trended'. However, although A level maths is considered a desirable qualification for technicians, there is no set requirement — not even a GCSE grade, though the fact that technicians will normally have a college qualification (HND, BTEC, etc) in chemistry or a related area means that they will likely have qualified in mathematics to at least GCSE level.

Case Study 3 is a small biotechnology company which operates with venture capital funding and is developing some of the new generation of cancer treatments. It has close ties with a university medical school. It currently operates with a very high ratio of scientists to technicians, and with a very informal, team-based structure. Scrupulous quality control is a vital element of its procedures, since it is critical not only that experimental findings are robust but also that they can be audited in depth by government or by prospective partners in the industry, at the time when production goes commercial in scale. Development is built around the generation of enormous quantities of data, which must be stored in clearly structured data bases: and the material on which the experimental work is carried out also has to be stored and catalogued with precision. A high degree of motivation and creativity is expected of all team members, including technicians.

Monitoring and Quality Control

CS1: Given the new quality control requirements it is crucial that products are traceable (in case of a fault found in one), and that all stock is logged (to keep track of shelf life etc). New skills required for these tasks involve following instructions precisely, in detail and systematically; scripting and logging of procedures; entering data into a computer or reading computer printouts in numerical or graphical form.

CS2: Monitoring of drugs is a central task of the laboratory, and sophisticated procedures and computer databases are in place. QC procedures take the form of ensuring the accuracy of analyses by employees cross-checking each other's analyses; this entails a need for sound communication skills, involving mathematical information.

CS3: Monitoring measurements of phenomenal amounts of data.

Concentration and dilution

An essential basic chemistry skill that was reported to be problematic in all three case studies is the preparation of solutions to specified concentrations, and taking a solution and diluting it down to a new concentration.

CS1 is a manufacturing context, which implies developing a stable, robust process for calculations that will then not change for a long time.

CS2 is an R&D context, so the work is variable over time and the need for a flexibility in doing concentration calculations is much more important (CS3 is a similar situation):

> When we do analyses of anything, comparisons against standards are vital and it's essential that people understand what they are doing. We do find that many junior people, graduates included, struggle to do dilution calculations.
>
> *Interviewer*: *And how do you deal with that problem, to train them?*
>
> We deal with it on a one to one basis, show them where they've gone wrong and hope they pick it up. It tends to be you only need to do that whilst you're doing the method development. Once the method is written down, it's all documented.

Note here that the problems with understanding concentration applied to both technician and graduate employees. There is an expectation that technicians should be able to do simple calculations of dilution 'in your head' and this was not perceived to be done well enough (but we only have evidence of this from senior managers, not *in situ* observations of what actually happens).

Statistical thinking

In all the case studies, all chemical analysis procedures are done by computer or are closely-specified by a script/QC mechanism. What the operator or technician needs, therefore, is an awareness/appreciation of certain 'basic' statistical principles; in CS1, this is the normal distribution; in CS2, appreciating the reliability of statistical models, especially when the number of data points is small.

CS1: Variability: Understanding accuracy and error (upper and lower bounds), that variation is inevitable and cumulative. (In the interview, the manager seemed to refer to a kind of 'mental picture' of the normal distribution as the way he himself thinks about it.)

CS2: Data trending, time series analysis and correlation between variables. Training in statistics is given to most staff, but the tendency is that 'they have the knowledge of what the statistical terms mean but they don't understand the philosophy' (manager's comment).

CS3: Clinical trials: 'discover things' by looking at spreadsheet data; systematic errors in measurement.

Influences of computerisation

CS1: a developing situation. The skills required from employees are changing, and this is challenging for older, experienced staff who do not possess IT skills. Largely concerned with reading and interpreting data for monitoring processes (numerical or graphical data); plus data entry, and accessing database.

CS2: a mature situation, so although rather complex (with a sophisticated information database, statistical software, and Word/Excel for reporting and simple statistical analysis) there is an established culture for the development of IT skills.

CS3: highly sophisticated machines dealing with phenomenal amount of data and feedback (graphical and numerical) from complex models.

Mathematical skills

- long term data analysis for tracking down measuring errors, spotting 'new things', dangers to quality control.
- understanding intensive quantities and being able to work out dilution calculations.
- being able to deal with relationships between numbers, percentage change, mentally and fluently.
- understanding exponentials and powers (CS3).
- working precisely and systematically but knowing when to estimate.
- skills in communicating mathematical information.
- statistical thinking: variability, trend, nature of trials and controls.

Tourism

Introduction

Three tourist-related companies/organisations were surveyed:

- Case Study 1: Medium-sized resort hotel.
- Case Study 2: Large city-centre conference hotel.
- Case Study 3: 'Eco-tourism' site, with scientific and conservation objectives plus large number of visitors.

Mathematical qualifications and skills demanded

Looking at the mathematical skills currently required in this sector, and at how they have evolved in the last decade, it is clear that, for the foreseeable future, many jobs will continue to demand little in the way of intermediate, let alone advanced, mathematical skills. This is evident both from our case studies and from frequent skill surveys, both national and international. Conventional wisdom in this sector has involved arguing that a move to a 'high skills' sector is necessary and should be encouraged and promoted by government policy. However, more recent surveys and studies have questioned this.

Of particular interest is Keep's work for the Skills Task Force (Skills Task Force, 1999). Keep confirms the generally low levels of skills and high turnover in the 'leisure' workforce, including hotels, restaurants and tourist attractions: but argues that this may be a perfectly sensible strategy, and one which is very stable in the medium term, since its corollary is low wage rates. Much of this sector, he argues, is very sensitive to price. This is especially true among home consumers; but among overseas visitors, many customers are also looking for low prices and special deals, and are working within tight budgets. It is not at all obvious that, for most operators, a move to higher skills is either possible (especially in a tight labour market such as most regions of England are currently experiencing) or would pay off in terms of major productivity rises. More recently, comparative European work has emphasised that much work in the tourism sector is low-skilled, and has not changed much in recent years. For such jobs, few mathematical qualifications (or formal qualifications of any sort) are required. In some other long-established types of job (notably catering) traditional vocational qualifications remain very important; and it is assumed by employers that they will incorporate required mathematical competencies.

In carrying out the case studies in this sector, we took note of these prior studies, and also of the way the sector has evolved in recent years. There has been enormous consolidation of the number of hotel chains: most city hotels (including those in suburban areas, with a largely business clientele, as well as those serving overseas package deals) belong to a very few groups – far fewer than the number of names would suggest. Alongside these, one finds small family hotels, usually in areas where there is little local competition, and top-of-the-market niche players – both in cities and in country areas. (Though note that many of these are also owned largely or completely by large companies.) Tourist attractions are a more diverse sector, not least because there are many not-for-profit organisations involved: but again, in terms of turnover, a few large players dominate (whether private – and running Alton Towers – or public – and 'operating' the Tower of London, or Stourhead.) In the restaurant industry, there has again been a growth in chains (often owned by very large companies with many different ‘brands’) alongside top-of-the-market niche players (who take cost control quite as seriously as do the multiples) and small, local concerns whose competitive advantage tends to be the low wages they pay. The result is that, for large parts of the tourism sector, traditional, low-qualification routes remain: but alongside them, in large hotel chains and attractions, there is a move towards hiring graduates and a demand for mathematically literate employees with IT skills. In jobs where, in the past, 18 year olds with ONDs or BTEC Nationals were hired, there is now a trend to employ graduates.

Ongoing training and development

Training priorities tend to be mostly focused on ‘soft’, customer service skills. Indeed, in the hotel sector, there has been something of a de-skilling of mid-level employees with respect to mathematics requirements. However, in other jobs, both in tourist attractions and in hotels, the level of mathematical literacy required has increased and is more and more vital to competitive success, and also closely bound up with the growth of IT-based operations.

The contextualised nature of mathematical activities

Our first two case studies were in the hotel sub-sector, where, as noted above, there has been rapid change in recent years, most visibly in the emergence of a few, very large multi-hotel groups. Our findings underline the way in which the management structure and operating pattern of a hotel depends crucially on its type. CS1 was an independent, privately run seaside resort hotel, with few competitors nearby. Hence, the prices it can charge vary little and the majority of guests are regulars. CS2 was a city centre hotel, and part of one of the very large hotel groups. CS2 is constantly in competition with numerous other hotels nearby, adjusting its rates dynamically (thanks to sophisticated computer software) according to date and type of customer. A very small and ever diminishing proportion of its bookings are made by individuals direct to the hotel. By contrast, an ‘intimate’ customer relationship of host and guest, and frequent re-bookings, was central to the business of CS1. A more formal, mathematicised approach to management was just being introduced at CS1, with the appointment of the first general manager: while in CS2, a sizeable number of management level personnel operated in this way. Nonetheless, in both hotels, a very large proportion of staff (waiters, porters, chambermaids, etc) were in jobs where there was no perceived need for intermediate mathematics skills.

The same pattern was evident in CS3. A small number of managerial staff are required: the site has a successful restaurant, and, as noted above, the traditional need to control costs in a low-margin business is even more pressing today than in the past. But most staff who are in contact with tourists (as opposed to the managers or, in this case, the on-site scientists) need high levels of ‘customer contact’ skill but not much mathematics.

In restaurants, the cost control and pricing skills required have, by contrast, changed rather little in recent years, although the number of outlets which have standardised menus and prices/portion rules set by central office is almost certainly much higher in percentage terms than 10, let alone 20, years ago. There is still a strong demand for chefs and restaurant/food service staff with the requisite mathematical abilities (and the other capacities needed to turn the calculations into cost control on the ground...) Finally, it is clear that the types of skill required, and the way in which they are spread through the organisation remains highly sensitive to the nature and location of the operation – and very different in a small isolated and traditional sea side hotel compared with a major hotel in a city centre.

Using data in the drive for efficiency

It is among managers that intermediate mathematical skills are most in evidence, and that skill needs have evolved, in particular with respect to data manipulation and use, and in the context of efficiency drives which affect some (not all) of the sector. Hotel managers will typically have worked in a number of more 'hands-on' roles before taking on positions in which mathematical skills become critically important. In the past, the typical route in was via a BTEC National level qualification, or perhaps an HND: today, there appears to be a growing preference for graduates (possibly with a degree in hotel management, but not necessarily). There is a perception that the typical 18 year old BTEC diploma holder is of a lower quality than in the past, although this may reflect the increasing tendency of young people to go to university and thus the non-availability of 18 year olds who are comparable to entrants in the past, rather than any change in qualification content and standard. Among candidates for managerial jobs, A level mathematics would be a rarity and the managers interviewed noted that one cannot take adequate mathematical skills for granted. This is one reason why, in the large chains, it is very common to use tests for applicants, which are developed for the hotel industry by a specialist US-based test developer. These tests examine applied budgeting and related skills among other things.

Management level staff in large hotels in competitive environments are responsible for, among other things:

1. Calculating and monitoring a set of quantifiable variables that capture the hotel's performance e.g. occupancy rate, revenue per available room (the price of room minus the cost of its upkeep including laundry, housekeeping, consumables), meal 'cost' (i.e. food plus service, condiments, etc.).

2. Identifying trends and dips and explaining why, both in terms of recent performance and by comparison with previous years and/or comparable hotels.

3. Identifying and costing capital investments, communicating a case for these and making an estimate of the increased profit it will generate over a period of time.

In a large hotel such as CS2, the general manager will be delegating and outsourcing most aspects of these activities. In a formally organised small hotel, the general manager will have a 'hands on' role in the hotel's development, working on a whole project through to completion. The 'tourist attraction' sub-sector mirrors this division of labour.

In addition, there is a major difference between the large hotel chains and the small niche players in the way room rates are determined, and in the consequent need for staff to estimate likely risks and returns associated with different and ever-changing pricing strategies. For CS1, there is a price for each room according to season. No overbooking or juggling of bookings is allowed. For CS2, there may be as many as 400 different rates active in the computer system at one time, depending not only on dates, but length of stay and type of customer (tourist rate, regular business booking from a certain company, one-off business booking, etc). The juggling of bookings is constant. The capacity to 'call' the prices right, to secure both good block-bookings from corporate customers and maintain a high occupancy rate which is also a profitable one, is now central to success in this part of the hotel sector. It has developed alongside the ever-increasing use of websites and agents to sell rooms, at competitive rates: and has, at one and the same time, deskilled the front-desk team (who are not involved in bookings) and created a new demand for highly skilled office-based sales teams able to operate, in a more or less intuitive way, with quite complex estimates of probability and risk.

IT skill needs

We have identified several areas in which intermediate mathematical skills were integrated with sophisticated IT use, reflecting the increasing importance of IT in (again) parts of the sector. They were:

- statistical analysis of trends and associated forecasting: based on data generated by the (IT-based) bookings system, but also involving creation of new variables and their analysis on Excel spreadsheets. The type of operation of CS2 entails very detailed analysis of past data and forecasting of future trends, and constant monitoring of key measures like income per room. This is high-level work, done only by senior staff, and far more prevalent in large hotels and chains than in small hotels or small tourist sites.

- decisions on how to set rates/what different rates to offer and on how to move bookings (bedrooms and meeting/conference bookings) between different rooms, based on appraisals of current and likely future occupancy trends. This set of skills involves more staff than the two previous ones: and is carried out on a continuous basis in relation to incoming data from multiple sources on the current state of bookings, and on competitors' practices.

- high-level thinking involved in costing new initiatives on the basis of predicted greater guest satisfaction and increased occupancy.

- rapid mental calculation and approximation (and also more formal calculator-based budgeting). Staff of whom this is required include conference booking staff (in big hotels) since rates are not preset and there have to be frequent judgments about, for example, the desirability of taking a cut on delegate fees in the expectation of making extra money on equipment hire. The same skills are required of chefs, in all levels and parts of the sector, to maximise profit on meals served each day, and in relation to the fresh ingredients available, cost of transportation and skills available in kitchen, and changing trends in guest tastes. This involves mathematical judgment intermingled with situated knowledge. It is not precise and errors of predicted costs tend to even out over time.

All of these skills are currently felt to be in short supply, although they are not top of most managers' 'skill shortage' list. Even in less automated small hotels there is a growing shortage of computer skills (involving systematic data input and checking) combined with traditional customer care.

Part 3: The Case Studies

Electronic Engineering and Optoelectronics

Case Study 1

No. of Employees	~30
Sector / Sub-sector	Electronics/Optoelectronics
Region	West Midlands
Profile of (maths) skills	8 degree level engineers 6 PhD science/engineering 4 UG engineers with A level 4 via apprenticeships with O level
Min. maths qualification	C or above at GCSE level for technician grades
Other qualifications	‘Initiative’ most important
Entry tests	No
Length of time company in operation	Company launched in early summer 2001.
Comment on turnover and perception of skill shortage	Recruitment volatile, some turnover at technician level within first 6 months of operation.
Is there training ‘on the job’ and if so, what?	Not at present. Company looking to develop ‘innovative’ disposition in employees

Much recruitment, and particularly the need for higher level mathematical skills, is driven by the company’s situation as a new business with the running, organisation and production processes still under development. This impacts on mathematical skills and needs in that jobs currently requiring high levels of mathematics are intended to become jobs requiring lower level mathematical skills as the company evolves. However, the company’s current needs are focused on innovation and ability to work in fast-changing circumstances, rather than tied to specific high-level mathematical qualifications: the company recruited two people with the expectation of good mathematical skills (both had science/engineering degrees) but a lack of ability to relate these to other skills, e.g. the need to communicate mathematical ideas to others, meant that these people were no longer employed by the company.

It was felt that that the types of mathematical skills developed by people, even at the degree level, are not necessarily the types of skills which (a) a company expects people of this level to possess or (b) the skills a company of this type wants — these include skills which are a combination of different ‘key’ skills, e.g. *communicating mathematical ideas*. In this light, the educational practice of dividing key skills into distinct areas is questionable.

The company is currently ‘top heavy’ in respect of mathematical skills and qualifications. Indeed ‘technician’ roles are being filled by new graduates of engineering disciplines. At the same time, two other recruits (a process engineer and a packaging engineer) did not have degrees but did use a higher level of mathematical skills than would normally be associated with their technician training. A key attribute for employees in this type of environment was felt to be 'adaptability' rather than learnt skills. By virtue of their science/engineering backgrounds, employees are expected to have developed sound mathematical *and* IT skills alongside domain expertise.

Employees at the technician level would need to be independent thinkers who did not require constant instruction or supervision. They would not need to know the ins and outs of the (engineering/optical) theory involved but would need to comprehend what they were doing and to make decisions on the basis of this.

As is typical of small and medium size enterprises (SMEs), the ability to be a 'jack-of-all-trades' was in evidence. Employees need to be adaptable to take on tasks and roles they may not necessarily have originally trained for and this may include operating with mathematical skills above those acquired in training.

The main intermediate mathematical skills identified in the particular job observed centred around understanding the relationships between variables, changing variables and evaluating outcomes; interpreting graphical representations and images and relating these to the processes under test; communicating mathematical information to someone with higher level mathematical and optics-related skills.

Case Study 2

No. of Employees	220
Sector / Sub-sector	Electronics/Optoelectronics
Region	South West
Profile of (maths) skills	120 'skilled men' via apprenticeships with O/GCSE level maths 20 engineers with HNC/HND/degree 1 PhD science
Min. maths qualification	C or above at GCSE level for apprenticeship entry
Other qualifications	No, need to be targeted to job
Entry tests	Yes, designed in collaboration with local FE College
Length of time company in operation	Since 1937
Comment on turnover and perception of skill shortage	Very little turnover, increasingly there is a 'qualification inflation' i.e. recruiting at higher levels than previously
Is there training 'on the job' and if so, what?	Yes, in sense that apprentices spend time in several departments. Employees expected to 'grow into job' on ongoing basis i.e. adapt to change and gain new skills

The case study site is one of two sites within the company, which has recently been taken over by a multi-national. 220 people are employed on the site with 120 on the 'shop floor' and 10 apprentices. The organisation is divided into areas of activity with, for example, a Finance and IT section and an Engineering section (with further sub-divisions of engineering). The average length of service of an employee is 19 years, many of the employees having joined the company upon leaving school and working their way through the company, taking qualifications whilst employed.

The company employs a group of people as 'skilled men' and this group would not normally possess mathematics at A level. The role of skilled men varies depending on which part of the factory they work in. Typically, they are involved in calculations, monitoring and reading equipment, extrapolating results and making inferences, but in relation to many different types of work.

Within the company the biggest mathematical need was for an understanding of trigonometry and many employees needed to work with geometry in different ways and to different levels.

Case Study 3

No. of Employees	~350 (in UK manufacturing site)
Sector / Sub-sector	Optoelectronics
Region	South East England
Profile of (maths) skills	Operators (GCSEs for workers in automated sections; no requirement for non-automated operators) Technicians (HNC, HND) Engineers/Senior Engineers (Degrees in Engineering, Science, Mathematics)
Min. maths qualification	None
Other qualifications	For operators, at least 5 GCSEs preferred, including Maths, at grades A to C. In the current economic climate, there is a move to recruitment of people with previous experience.
Entry tests	Yes: Numeracy, literacy, attention to detail, manual dexterity, etc (all outsourced to an agency)
Length of time company in operation	13 years
Comment on turnover and perception of skill shortage	For operators, there is a definite lack of understanding of negative numbers. For Engineers, a lack of familiarity in Excel and its mathematical functions.
Is there training 'on the job' and if so, what?	Operator recruits are given comprehensive initial training focussed on their job assignment; for those working on automated machines this will include maths and problem-solving, for dealing with Statistical Process Control. At higher levels, training has an 'individual' element — e.g. personal development sessions for line leaders.

The site for this case study was the manufacturing division of a company that designs and produces optoelectronic components for fibre-optic telecommunications, which are supplied to some of the leading telecomm equipment manufacturers in the world. The products are based on a proprietary technology, which took about 10 years of R & D to 'bring to market', with manufacturing commencing only in 1998.

The technology is a hybrid of conventional semiconductor technology and special optoelectronic designs, and it follows from this that the manufacturing process involves high-volume, automated semiconductor fabrication combined with a lot of highly-skilled manual work to assemble the optoelectronic components. However, some of the assembly work is done by machine, under the control of a skilled operator. Components need many checks, and at the moment this is done by operators manually placing sample components into testing machinery (though machinery is available to link assembly tools with testing tools, and to have automatic feedback corrections, the company has not acquired any of these yet).

The manufacturing process is monitored using Statistical Process Control (SPC) techniques and there is an intention to implement in the near future the Six Sigma methodology to significantly reduce the number of defective products. This requires a numerate and literate workforce (preparation for which is already in hand by the use of numeracy entry tests), but more especially it requires changes to the ‘communication culture’ of the company.

Example: Number skills – Working with negative numbers

A manufacturing engineer described a recent problem where some machine operators lacked an ability to work with negative numbers. Automatic machines place parts onto a ceramic ‘tile’ by locating reference marks printed on the tile (which have known coordinates) and putting parts down at specified (x,y) coordinates. Operators have to check a sample of the finished components to ensure that the machine’s placing is correct, which requires determining the coordinates of the (diagonally-opposite) corners of a rectangular part. The testing machine will calculate the coordinates, but the operator has to take that information and enter it into the SPC charts. The problem emerged as managers began to see ‘strange’ SPC charts being produced, and eventually it was realised that a small number of operators were ignoring the negative signs in front of coordinates:

> The problem only became apparent recently when we installed more of these PC-based process control charts. The original group were very good, but when we expanded to a larger group we realised that some were recording the data wrongly. The problem showed up because if your measurements have a good offset then you never see negative values, but in this particular measurement the centring is around zero.

The response was for the manufacturing manager to offer one-to-one advice to the particular operators identified, and also general training was given to all operators about taking measurements and constructing SPC charts.

The negative numbers problem suggests, perhaps, that mathematical skills are a more problematic area than the company had previously realised:

> We’ve never paid a lot of attention to mathematical skills, until the instance came up with the negative numbers, which our entry tests don’t cover. So we’ve become more aware of it. … I’m worried that people come in not understanding averages, and the reasons for them, and I was absolutely amazed about the negative numbers. … The level of maths covered in GCSE is higher than most of what we use here, so I don’t think it’s a problem of curriculum, but motivation or attention… I don’t see a lack of ability, some operators can work out permutations and combinations in their heads, but simple things like averaging and negative numbers, they couldn’t put together.

Financial Services (Retail)

Case Study 1

No. of employees	about 1000
Sector:	Financial services
Region:	East of England
Profile of mathematical skills	Qualifications of staff not kept to hand, but top third of workforce should be able to understand performance charts and cash flow data, spot errors and exceptions, carry out basic statistical analyses
Minimum maths qualification:	GCSE C
Entry tests:	Intermittently
Length of time in operation:	Over 100 years, but big merger 10 years ago
Comment on turnover:	Low: even those recruited from outside the company overwhelmingly come from other building societies
Is there training on the job:	Yes: lots but almost all provided on fairly ad hoc basis in house. A bit of 'bought in' training on Excel but this was very procedural.

The building society in this study is medium-sized for the industry, though growing rapidly, and is staffed overwhelmingly by people whose whole working life has been spent either in that society, or in building societies generally. The tradition is very much one of promotion from within, and of a stable staff. The management structure is quite flat, and the atmosphere informal. Although the headquarters is in a modern out-of-town office park, the society itself is very much rooted in the surrounding counties with a strong commitment to maintaining its branch network and local presence.

Society operations are all IT-based and built around the central system, which is a partially-customised industry standard. However, many operations are not fully integrated into this central system: among them, those associated with customer insurance. Mortgage customers can elect to take out a combined (building + contents) or a buildings-only insurance policy through the company. A large proportion of the resulting transactions will be automatically calculated within the system, when the customer's details are entered; but there will also often be back-dating of transactions, which must be done manually. This may be because of delays in setting up accounts; or because the customer cancels the authority (and, within a set period, can reclaim payments already made) and manual entry of refunds is needed; or, on occasion, because re-mortgaging leads to customers making double payments which it takes time for them to notice.

Case Study 2

No. of employees	about 100
Sector:	Financial services
Region:	South East
Profile of maths skills	All need at least GCSE C-type proficiency and 30-40% need to go beyond the minimum. Need at least one chartered accountant: currently have 4. Several managers have degrees but these not required for the jobs.
Minimum maths qualification:	GCSE C
Entry tests:	No: but competency tests for certain internal promotions/mandates
Length of time in operation:	Over 100 years
Comment on turnover:	Low
Is there training on the job:	Yes, but the only really 'formalised' part is leading up to/ precondition for granting lending mandates. Regular training sessions on, e.g., new regulations; refresher training for underwriters around case studies. Staff encouraged to obtain banking/insurance/mortgage qualifications but these done in own time.

This is a small, long-established building society, which does relatively little out-of-area lending, and is firmly rooted in the local economy. It has benefited from the transformation of that economy, as new industries have developed and located in the area, attracted by good communications and a well-educated workforce.

This case study illustrates how the whole sector, including smaller 'traditional' enterprises, has been affected by the development of IT, the increasing competitiveness of the financial services industry, and customers' growing tendency to shop around and re-mortgage frequently. When the society has additional funds that it wants to lend, and designs new products, it is very conscious of the importance of potential customers who are attracted through internet sites: and its internal operations are built around an integrated, IT-based central system. At the same time, its recruitment and personnel policies continue to emphasise internal promotion, and it has extremely low staff turnover. Many staff currently working at the society will have progressed through hand-held calculators to a few free-standing computers before moving to the current integrated set-up (all on the basis of internal training and learning on the job).

Case Study 3

No. employees	~ 700
Sector:	Financial
Region:	South West
Profile of maths skills	11 groups (pensions, legal, marketing, human resources (10 people), customer services including contact centre (200), service, actuarial, facilities, IT, Unit Trust, PFAs, (advisory to help policy holders)
Minimum maths qualification:	C or above at GCSE for Customer Services and PFAs
Entry tests:	Give numeracy tests as well as GCSE Maths grade C (to find exceptions)
Length of time in operation:	Since 1984
Comment on turnover and perception of skill shortage:	Full quota now after recruitment drive
Is there training on the job:	Mixture of training plus encouragement to study (with financial support)

This is a medium-sized financial services group, recently consolidated on one site, and providing a range of personal and investment products. All sections of work are target-driven, and most employees deal directly with customers, offering advice and information. Anything specialised/problematic will be passed on to out-sourced sections, in other more specialised companies.

This study was curtailed due to the impossibility of arranging a site visit following on from the initial telephone interview.

Food Processing

Case Study 1

No. of Employees	1800 on 2 production sites (1 site visited)
Sector / Sub-sector	Food processing
Region	Yorkshire Forward
Profile of (maths) skills	Over 500 line workers ('SL1 & 2') (no qualifications required but must pass numeracy entry test) ~120 line technicians ('SL3') (probably GCSE Maths but can move up from SL1 & 2 levels) ~45 shift technicians ('SL6') (qualified to HNC/HND or university level) 14 on management team.
Min. maths qualification	None demanded
Other qualifications	Increasingly concerned with 'attitude' as precursor to investing in skills development
Entry tests	Yes, including key skill and specific skills tests. Nature and scope of tests applied is dependent on level of recruitment.
Length of time company in operation	40 years on 1 site, 50 years on 2nd site (family business pre-1945)
Comment on turnover and perception of skill shortage	Very low turnover. Up to supervisory level no problem in recruitment but expect to invest heavily in skills development. Supervisory level & above - some difficulties in recruitment (due to local & national issues in sector)
Is there training 'on the job' and if so, what?	Yes. Average of 3.75% of employees' time spent on training & development annually. Approx. £500k per year T & D budget.

The company consists of a number of production facilities, including the two sites located within the Yorkshire Forward region, and is part of a larger parent company with wide-ranging interests. The company has a long-standing presence in the area with the location being closely tied to the food dealt with. The two production facilities have a different product focus with one concerned with the production of frozen meals and the other dealing with frozen fish & vegetables. The company has an excellent reputation for pay and conditions, reflected in the little difficulty experienced in recruiting to many roles. Recruitment to higher levels in the company is currently problematic, believed to be widespread in industry at the present time, but also relating to strong competition locally (both in food and non-food sectors).

The culture of the company was described as 'a little bit different' for the food industry in general, in part driven by their position within the larger conglomerate. Approximately four years ago the company reviewed its future role, especially with respect to manufacturing capabilities, in relation to the parent company. There was a need to compete and be successful within the conglomerate as well as in comparison with the general food production sector since the parent company is concerned less with the particular sector than with the success of its overall portfolio of concerns and brands.

In order to compete in the market place and within the parent company the management structures were revised and the company moved towards a high intervention strategy with employees, producing a skills-based pay structure and positively encouraging progression within the company. This was also, in part, in response to external shortages of qualified staff.

The resulting structure, described as ‘tight and flat’ includes a management team of 14, a supervisory level and a range of ‘technicians’ levels. The structure is both skills and qualifications related, for example, Engineering Technicians (‘Skill Level 6’) would be qualified to HNC/HND or university level. SL3 employees are ‘line assigned’ and would use tools, be process workers with mechanical experience and mathematics would be important in their duties. They have a high degree of autonomy and the company has invested heavily in key skills development at this level. Each role within the company has an associated skills & competencies matrix.

Recruits into SL1 and 2 would not necessarily have a GCSE mathematics qualification, SL3 and above would probably have GCSE as a minimum. The company is less concerned with precise qualifications than with identifying current skills and aptitude/attitude and then investing in skill development.

Case Study 2

No. of Employees	6
Sector / Sub-sector	Food processing / marketing
Region	East Anglia
Profile of (maths) skills	2 with degrees which include business applications. 3 with O level Maths or GCSE C+. 1 no formal maths
Min. maths qualification	GCSE C or above (B strongly preferred)
Other qualifications	Common sense, judgement, work ethic
Entry tests	Yes
Length of time company in operation	5 years
Comment on turnover and perception of skill shortage	Rural area so good people stay, *when* you can get them.
Is there training 'on the job' and if so, what?	Will give software training if needed. Also support independent self-study

A marketing/publicity/advice organisation providing services to member companies which are mostly small, and it has recently started an internet-based sales and distribution service. The mathematics-related skills needed by employees were viewed as generic and relating to the activities of the company (advice, sales and distribution) rather than relating to this particular industrial sector. It was useful for people to know something specific about the food sector but this was secondary.

The CEO felt that everyone in the organisation must be functioning at a level well above what he would consider to be basic numeracy and would need wide-ranging skills such as calculating, manipulating mathematical information, using data in tables, charts and graphs, and interpreting and communicating mathematical information. They needed to be comfortable thinking through and working with basic business problems and scenarios – to work out what is needed for a given yield, to see what they should sell on at for something bought in at cost: and they need real familiarity with Excel. There was a strong emphasis on the need for people to notice that something doesn't make sense in a spreadsheet or set of figures. Development of these mathematical skills was always on the job.

Employees were engaged in promotional activities which required budgeting and other costings work. 'Person skills' were reported as more essential and yet company activity was tied to employees' abilities to work with data, understand mathematical information in spreadsheets and, in the case of some employees, work with complex accounting software. This accountancy software is used to monitor and run the distribution element of the company as well as payroll etc. The distribution aspect is in its infancy and they are beginning to build up a product history to help develop an understanding of the logistics of distribution and with a view to predicting future demands and stock to be held.

Case Study 3

No. of Employees	13 (on part-time hours) + 2 owners/managers
Sector / Sub-sector	Food processing
Region	East of England
Profile of (maths) skills	Owner-managers have diplomas in Farm Business Management and Advanced Business Management Cooks Order-taking, packing, dispatching (3) Delivery driver (1)
Min. maths qualification	None
Other qualifications	Nothing specific. 'Good English' and ability to do mental arithmetic, use a calculator, (learn how to) use a spreadsheet. 'Attention to detail' is most highly-valued
Entry tests	No
Length of time company in operation	14 years
Comment on turnover and perception of skill shortage	Difficult to find enough staff (this is the limiting factor on bakery output). No particular feeling about skills shortage.
Is there training 'on the job' and if so, what?	Staff can be day-released for training, but the government-backed training that's available locally is all IT-focused when what are needed are specific practical skills in baking. IT skills (mostly working with spreadsheets) are best developed informally with experience

The bakery developed from a small, kitchen-based operation (25 cakes a week being sold through the Women's Institute) to a more professional operation with its own baking ovens, and then through steady growth up to the present time. There is physical capacity for further growth of output, but this is being limited by the difficulty of finding additional staff. The bakery is family-owned and run, and operates as a diversification enterprise of a farm. As such, the development aim is to expand the business without taking any undue risk.

The bakery produces to order from a range of about 75 different products (cakes and biscuits). It uses home-style recipes without any preservatives, so to guarantee freshness it only bakes what has been ordered by customers, and for the most part delivers directly to them, using different, regular delivery routes on each day of the week. There are about 50 customers at present (both retail and catering): some make two or three orders per week, but most only one, because of their distance away for delivery.

The tight running of the bakery depends to a large extent on the use of spreadsheet software (Excel) to store information. As the business has grown in scale, so has the amount of data to be handled, and spreadsheets have taken on a central role. The bakery staff are only users of the sheets and any development work is done by temporary staff who already possess appropriate IT skills:

The bakery operation features little use of intermediate maths skills, though effective and accurate use of spreadsheet software is central to the bakery's operations. This does seem like a good example of how many small businesses must be using spreadsheets—in a semi-automated way, using the tabulation and data-storage of the sheet to support employees' implicit judgments, mental notes and mental calculations.

The use of spreadsheets has 'streamlined' operations significantly for the bakery, but this process is only taken to a limited extent: there is no point, for example, in 'scientifically' forecasting product sales, when the bakery output is being limited by lack of staff.

Case Study 4

No. of Employees	650
Sector / Sub-sector	Food processing / Baking and ready-meals
Region	East Midlands
Profile of (maths) skills	Operators (450, no qualifications required), Line Leaders (in-house trained) Shift managers (70% time-served, 30% graduate) Senior management (graduates): Technical, personnel, logistics, finance, etc. Technical department (mainly graduate): separated into Quality Assurance and Process Development (new recipes and products)
Min. maths qualification	None; expectation that graduates will have good GCSE Maths in order to have gained their degree
Other qualifications	Preference for degrees in food science, or a biological science; but managers have varied degree background
Entry tests	Assessment Centre sessions for managerial-level recruitment
Length of time company in operation	20 years
Comment on turnover and perception of skill shortage	Low turnover of permanent staff; high turnover of temporary staff (varying anywhere between 10 & 150 from week to week). Trend to carry out more Quality Assurance procedures on the shop-floor: this requires general raising of levels of understanding by operators. SAP Business Management System recently introduced, so training needed at shop-floor on IT/spreadsheet skills.
Is there training 'on the job' and if so, what?	Yes. All shop-floor employees to gain NVQ Food Science levels 1 & 2 a within 5 years + Food safety, factory safety, etc. Line leaders trained in calculation and use of KPI (key performance indicators) efficiency measures (OEE, customer service, material usage and man-hours)

A company whose output divides 50-50 into savoury baked products (made on highly-automated lines) and ready-meals (produced much more manually); everything is produced under the labels of major supermarket customers. The company is a wholly-owned division of a major UK food producer, and although it operates independently on a day-to-day basis, the parent company is involved in many aspects: for example, a large proportion of management staff come to the company by way of the parent company's graduate training scheme. The parent company is also pushing for a move to devolve responsibility for process and quality control procedures down to the line operators; currently responsibility rests with managers. The company is in the process of implementing this movement but it was viewed as challenging as line workers would not be familiar with the data and abstract numerical information generally used in these processes.

The majority of employees are working on ready-meals, and this is an area undergoing a lot of change: customers are requiring new products with increasing frequency, with short life-cycles on each product. This is very demanding for the company because this kind of production is highly manual — the company can only invest in automated (and generally cheaper, more reliable) processes once a product has matured with a proven market. It is also difficult to quantify long-term trends in the business when the product base is changing so rapidly year-on-year.

The company uses Key Performance Indicators (KPIs) to monitor production. Line leaders collect raw data manually, which is keyed into spreadsheets by production managers. At the moment, there is no centralised database that would allow long-term analysis of this data, it is only used for short-term trends and process improvement. Quality is monitored by a Quality Assurance department, which collects data from all parts of the plant to ensure that specifications are being met.

The company is rolling out an NVQ programme for all line operators, going department by department over the next 5 years. This is aimed at enabling operators to become more motivated and involved in production and improvement.

Some views were expressed by managers here about the importance of mental arithmetic. A production manager mentioned the importance of being able to ‘work things out’ all the time, without needing a calculator, such as in ad hoc back-of-the-serviette calculations in the canteen. This skill was also felt to be important for line leaders, and a significant factor in what makes potential line leaders ‘shine’ among the pool of operators, because of their ability to quickly deal with problems on the production line.

Health Care

Case Study 1

No. of Employees	about 35, at manager/senior manager level
Sector / Sub-sector	Health Care / Management
Region	South East
Profile of (maths) skills	Increasing trend towards degree entry. No mathematics demanded (by chance people may have). Previously there was more promotion from, say, nursing.
Min. maths qualification	None
Other qualifications	No
Entry tests	No. Assume Excel skills for promotion.
Length of time in operation	Recent merger of two primary care groups.
Comment on turnover and perception of skill shortage	Need for analysts who understand what data mean in terms of NHS.
Is there training 'on the job' and if so, what?	Courses available in management.

This case study was based on a visit to a medium-size primary care group (PCG) that had recently merged with another PCG. There was a huge state of flux and change in the merger, and this has continued with the process of becoming a Primary Care Trust (in April 2002) which has taken over all health authority responsibilities. There is a hierarchical management structure. The case study focused on the role of managers/senior managers, and in particular on that of the commissioning managers who commission services for the PCG from acute trusts or other providers. Their job means reaching agreement on the quality, standard, and amount of service to buy or commission from a provider and how much this service will cost.

> Suppose there is statistical evidence to say that we actually need ten hip operations a year, let's say. So in the commissioning process we propose buying ten hip operations a year. The provider might argue with us and say well actually we did twelve for you last year. And then we think further and we might say, actually we need some more done.

These negotiations are subject to change given government directives, so the manager has to be able to re-model and re-cost:

> We do have government targets coming down to us saying nobody must wait more than x number of months etc, so we have obviously got to get more through… and therefore the Trust will say that in order to do that increased activity we actually want more money from you.

There is thus a need to make quick decisions in the light of new political imperatives, sometimes regardless of clinical judgement.

> You have got to look at all the individual patients. If Charlie only wants his varicose veins done but he has actually been waiting for twelve months, you have got to get that done. To hell with the fact that Fred has been waiting nine months for a heart by-pass operation, because the government will say Charlie must not wait more than twelve months.

Managers need to constantly monitor activity against targets and negotiated totals.

> You constantly say well we purchased 100 hips with that particular provider. You get to about September, halfway through the year (because the year is April to March), and say well they have only done, 25 of them and what are their plans to actually deliver the other 75, are they going to deliver them or not? And increasingly with the top down pressures from this government and so on, it has become a case of saying to the hospital 'if you are going to do them, you, the hospital, have got to be paying for them to be done privately'.

Thus there is a need to understand data that monitor individuals (has Fred been waiting 12 months?), alongside appreciation of general data about resources (available beds, cost of new beds, nurses to staff the greater number of beds, length of time to train a nurse, etc.).

Additionally, managers need strong financial skills so they are able to put together a bid for money (from new initiatives, i.e. staff, resources) that has a budget that is flexible (to allow virement, to assess the influences of this non-recurrent funding and available resources) and adequate.

To be able to monitor all these variables effectively, managers need to be able to read data presented in spreadsheet format and in graphs/ charts. Excel skills are assumed, although are not required to build the models or charts, but to understand how they are constructed, what they mean and any trends.

There is a general shortage of analysts who understand data in the context of the NHS: 'finding people that can take all this data and make it meaningful, and look at it and analyse trends'.

They need to be able to understand the language of the NHS and how the data are constructed in the context of care. Data is assessed in terms of a Finished Episode of Care. 'It includes your total hip operation, it includes your out patient appointment, all the tests you might have to have, all the follow-up out-patients appointments, it is all built in and cosseted. That means that from the minute the patient is referred to the hospital until the minute they are discharged.'

The impression from the case study was strong support for apprenticeship and for nurses to 'belong' to hospitals during their training so they would feel part of organisation.

Case Study 2

No. of Employees	140
Sector / Sub-sector	Health Care / Pathology laboratory
Region	South West
Profile of (maths) skills	100 graduate (and state-registered, medical and scientific degrees), 30 Medical Laboratory Assistants (MLAs) (GCSs)
Min. maths qualification	For MLAs, none specified; for graduates, GCSE Maths
Other qualifications	The most useful skills for MLAs, besides interpersonal skills, are computer literacy and keyboard (data entry) skills
Entry tests	Yes, for keyboard (data entry) skills
Length of time in operation	Over 30 years
Comment on turnover and perception of skill shortage	Lack of mental fluency with numbers (for checking calculator/computer calculations). Lack of ability with dilution and concentration calculations (but these are rarely used in a highly-automated lab)
Is there training 'on the job' and if so, what?	Graduate staff do masters-level courses to obtain state registration. MLAs will soon (2003?) be offered an NVQ (levels 2 and 3) programme.

This is a large pathology laboratory, serving the whole of an NHS Trust. The laboratory analyses all forms of body tissue, according to major divisions of biochemistry, haematology, (the blood and blood cells), histopathology (materials taken in operating theatres), microbiology (the organisms that are associated with the body). Historically these divisions operated quite separately, with different, specialised qualification routes to work in them. However, the recent trend is for merging, for example: 'you get combined departments now of haematology and biochemistry, because they tend to use similar levels of automation; technology has driven us, because most people are using the same sorts of technologies now'.

All the work of the laboratory is highly computerised and automated. When samples arrive in the lab to be tested, all the details are entered into a central computer database, which will then automatically trigger requests for particular samples to be delivered to the different analysis machines. Many of these machines are fully automatic, including directly delivering analysis results back to the database. Many analytical judgments are also automated: the database is programmed with 'logic rules', so that it is only when a result lies outside specified 'normal ranges' (e.g. for white blood cell count in a blood sample), that the computer system alerts a member of staff to investigate (authorise the result, or request further testing). Otherwise, it passes out of the lab without human scrutiny. This degree of automation is driven not only by the availability of technology, but by the huge volume of tests (e.g. 900 blood tests per day, each of which produces several dozen key numbers) that the lab must perform. Pathology labs have been computerised since the 1970s, so the use of IT is very mature.

In terms of this project's focus on 'technician/intermediate' grade staff, this case study is notable in that there is not such a staff grade. The majority of staff are degree-qualified, and are further required to do a masters-level course over a period of years to become state-registered, with a minority of Medical Laboratory Assistants (MLAs), with a minimal GCSE background, who assist in loading and unloading samples to the automatic analytical machines, and who may perform a few, still-unautomated analyses. *A basic operating principle is that judgments and interpretations of analytical results can only be made by state-registered staff.*

There were few instances of explicit mathematical work:

- establishing 'normal ranges' for new pieces of analytical equipment may need some consideration of normal distributions

- 2 and 3-dimensional representations of data were used, but mostly in the form of special charts specific to the practice, not general graphical representations

- Non-automated tests (which are not common) require some simple calculations with substituting values into algebraic formulae

The only area where significant mathematics was explicitly in use was for the researchers based in the lab, who develop 'leading edge' analytical techniques. A researcher commented that the research literature in the field has begun in recent years to use complex statistical techniques, which no-one in the lab at present has sufficient knowledge to properly understand:

> There are many papers being published now with these complex stats. Of course, they've been peer-reviewed, but all we can do at the moment is to use the conclusions made in the paper, we can't critically analyse their technique.

They are considering to send one of the junior researchers on an undergraduate statistics course, and make him/her something of a statistics specialist, in order to get the lab up to speed with international trends.

Example: Blood cell analysis and normal ranges

> *Interviewer: Could we focus on just one of the machines you have here, what that machine does for you? Let's take the big blood cell analyser.*
>
> That gives two kind of results, means of different quantities, or absolute numbers. We have normal ranges for the different numbers, and if the sample goes outside those we know there's a problem to check.
>
> *Interviewer: What happens if a sample is normal? And what happens when a sample is not normal?*
>
> We have normal ranges for everything. We set those for the analysers, and they will flag by colours any data outside normal. We have 'rules based authorization', so it's only samples that don't fit the rules which we will look at individually. Those come onto a queue within the computer database for us to authorise. We couldn't do 800 a day if we looked at each one individually.
>
> *Interviewer: So you're relying on the machine to be 100% accurate? Is that standard practice, or just this lab?*

Yes we do rely on them; these are procedures we've worked out here for ourselves. We've had nothing in four years of operation that was proven to be machine error. Things do go wrong, but I reckon it's always due to pressing a button incorrectly. We decided ourselves what ranges to put into the computer. We have normal ranges, corresponding to the normal population, and then abnormal ranges, which are wider. So a number can be outside a normal range, but not sufficiently outside for us to act on it.

Interviewer: How do you set those ranges?

We have to do the stats, find the mean and 2 standard deviations. Especially when we've got a new analyser, putting through 50 or 100 normal samples, to determine our normal range, and compare that to the manufacturer's which we hope will be similar. That is only every few years for a new machine. But we do have new tests introduced, where again ranges have to be established, comparing the new and old methods. But generally, it's true that we do not do much maths in haematology, because the analysers do so much for us.

Case Study 3

No. of Employees	60
Sector / Sub-sector	Health Care / Cancer therapy and radiography unit
Region	Yorkshire Forward
Profile of (maths) skills	Technical roles: Therapy radiographers (degree/HND), Physicists (degree), Dosimetrists (degree/HND), Technicians (HND or degree) Administrative roles: Data managers Clinical roles (not considered in the case study): Nurses, helpers, junior doctors, consultants etc.
Min. maths qualification	Nothing specified; assumption that HND or degree implies 'good' GCSE maths background
Other qualifications	Not specified in general; technical roles have specific defined entry routes
Entry tests	Practical tests for data managers
Length of time in operation	20 years plus
Comment on turnover and perception of skill shortage	Low turnover, but there is a 20% shortfall nationally for recruitment of therapy radiographers, and this unit has five current vacancies.
Is there training 'on the job' and if so, what?	Specific technical courses. Part-time MSc for radiographers to progress to 'advanced practitioner' level. Plans to introduce NVQ-based training for a new role of 'therapy assistant'.

The case study site was a cancer therapy and radiography unit, serving the needs of a large, urban NHS Trust. The unit has inpatient wards and an out patient centre, with a full complement of medical staff. However, the study focused only on the technical work of the unit, carrying out radiography treatments using highly complex linear accelerator X-ray machines.

There are four technical roles: Therapy radiographers, who administer treatment to patients; Dosimetrists, who plan radiography treatment with complex computer software (this is not a role that exists everywhere; it may be undertaken by experienced radiographers, which is what dosimetrists normally are); Physicists, who work on the more complex aspects of dealing with radiation (checking and calibrating the machines, and dealing with the planning for complicated tumours, especially in the head and neck, where large doses of radiation need to be delivered extremely carefully); and Technicians, who (despite the name) are very skilled, professionally-graded maintainers of the X-ray machines.

Dosimetrists and physicists work on the planning of treatments, using 3-dimensional scans of tumours and the surrounding body. Special computer software helps them to decide which directions to target the X ray beam, and what strength of radiation to apply to deliver the required dose in the tumour (which is decided by the doctor dealing with the case). Beams can be 'trimmed' using lead filters which shape the beam so as to avoid radiation striking healthy tissue—all of this is calculated by the software on the basis of the 3D patient data. Before the arrival of computer systems, treatment of this complexity simply did not exist. Calculations were done using formulae and lookup tables to calculate, say, the absorption factors of different body organs, and delivering radiation to adjacent healthy tissue was unavoidable.

From the planning, information is passed onto the therapy radiographer who delivers the treatment. Currently, this happens by the dosimetrist writing out a treatment card (specifying beam orientation, beam strength, etc); soon, all this will be computerised, with information passing electronically via a database.

Complex computer software, and complex electronic equipment, have become central to radiography work, and are making possible more and more complex treatments. It is a pertinent question whether the work has therefore become more or less mathematical. The opinion of the two radiographers interviewed was that it is definitely much less, and maths skills are becoming 'redundant': the software allows the radiographer/dosimetrist to focus on the details of the patient and the tumour, 'black boxing' the numerical calculations required.

Physicists are required to use a significant amount of trigonometry and algebra, but they do have a very thorough mathematical preparation (through A level, physics degree and often, masters in medical physics). This contrasts with the limited, possibly O level/GCSE mathematics background of the therapy radiographers and dosimetrists.

There was a problem reported in younger staff of not being able to visualise things well, and this may betray the situation that mathematical skills are actually not becoming redundant, but taking on an implicit role (something mental that 'rubs off' from the act of doing routine calculations). Geometry and trigonometry were essential skills for radiographers in the past. It was not clear how young radiographers are now acquiring these skills.

Example: Treatment planning

> *Interviewer: I'm wondering about the 3-dimensional aspects of what you do, thinking about the way something is pointing in space, do you think of that as mathematical?*
>
> Well, when I'm on the computer, there's a 3-D view window which allows me to 'walk around the patient', and I can see if the tumour is pointing out of the dose area, which tells me the collimators are not wide enough, they have to be increased.
>
> *Interviewer: Is that fairly recent technology?*
>
> Yes, only in the last 2 years. Before then, we had to look at it in 2D, and just do it, looking at the dose on every slice of the CT scan.
>
> *Interviewer: What do you feel is the trend with the technology, relative to doing calculations?*
>
> When I started it was all hand calculation, and we didn't have the linear accelerators. The more technology we get, the more complicated we're getting in dealing with problems. We have the facility now to go for more perfection than we used to.
>
> *Interviewer: In terms of say, 'I want a perfect shot, no touching of other tissue'?*

Right. For example with the kidneys, we weren’t able to work out what dose was going through to the kidney. Now we have the dose volume histogram, and the computer will work that the kidney is getting, say, 20 Gray. And as you look at it, you say to yourself that’s not quite right, I want to modify it a bit.

Packaging

Case Study 1

No. of Employees	220
Sector / Sub-sector	Packaging / Paper cartons
Region	South East
Profile of (maths) skills	4 degrees (business, engineering, economics, music) 11/12 A Level (Maths not singled out) 50/55 GCSE
Min. maths qualification	None
Other qualifications	None specified
Entry tests	Numeracy (and literacy) tests at each level: administration and shop floor; middle management; graduate.
Length of time company in operation	Parent company is 70 years old. This site taken over in 1993 (95% of staff stayed).
Comment on turnover and perception of skill shortage	Very low turnover (a few people per year). No particular skill shortage, but gap in multiple skills, i.e. technical combined with business/administration.
Is there training 'on the job' and if so, what?	Yes. Mainly training on job with some encouragement to study NVQs etc. ('Investors in People' scheme).

The site visited for this case study was the UK factory of a multinational 'jobber printer', making printed cartons on a contract basis. Contracts may be stand-alone or, increasingly, multinational contracts for corporate clients covering many countries and different types of carton.

Cartons are printed, cut out and creased on very high-speed, computerised printing presses. Typically, carton design is done by the client, but the company has to work out (nowadays, using computer software) how to optimally 'fill' the individual carton designs onto the raw cardboard sheet. Cartons leave the factory as flat sheets, which are then formed into box cartons at the client's packing plants.

The company has a strictly hierarchical management profile: shop floor; overseer in charge of monitoring quality of cartons, labels etc; technical manager in charge of particular area; works manager in charge of several areas; and a general manager of the site. All the managers are male, as are almost all of the employees.

The focus of the case study was on skills used by a works manager (WM) and how these skills need to be developed for promotion. The WM oversees 3 processes: litho, cut & crease, finishing. The WM's responsibilities are to:

- determine performance criteria.
- assess performance against criteria & targets in order to monitor & improve it
- cost a job.
- communicate complex information 'upwards and downwards'.

Example: Managing information to cost a job

> WM: Say the client puts that packet on the table and says 'I want 5 million of them', and I'm going to make it 5 times, 1 million each time … I would cost within 10-15%.
>
> *Interviewer: You could do that instantaneously? What's going through your head when you say it?*
>
> Number up on the sheet. How many colours it will be...
>
> *Interviewer: What's 'number up' on the sheet?*
>
> How many one of those individual little cartons can you fit on the sheets. … And how many colours, and the profile, the style of carton, is it a fast runner, or is it a slow runner… And then from there you would look at the details. … What we are finding now is that the market is toughening up. Customers issue quotations for lumps of business. And we have to make our own assumption on how to produce them. I'll give you an example: If a customer says 'I've got 120,000 cartons, I want you to produce that 12 times a year', if we quote the price of doing it 12 times a year, we would be dead in the water — 5 years ago we could do that. So what we'd do is say we'll manufacture it 4 times a year, and we'll deliver it 3 times from one batch.

Effective costing relies on understanding the variables of raw materials (costs, availability) and the capabilities of the printing machines (e.g. some risk assessment of having to deal with complicated art work, which may lead to a high rejection rate), as well as knowing what competitors may be working on, and the prices they are currently quoting. The trend towards contracts based on 'lumps of business' requires further management of variables, balancing the costs of storage of completed larger batches against the costs of printing in smaller batches.

Example: A works manager who could not 'concretise' data or 'abstract' information from data

A WM needs to manage information for:

- diagnosis of causes of low performance.
- identification of trends from numerical data.
- extraction of performance criteria, compared against targets.
- planning of corrective action and improvement; implications of new contracts and new machinery.

Furthermore, the WM must be able to communicate all this information to shop-floor and to senior management. The general manager described one works manager who could not manage and communicate information in this way:

> We had somebody who had been in the section a long, long time. He could not manage the six machines, the complexity of it… He found it very difficult to be able to juggle the dynamics of what was happening …. He could do the mechanics of it because he knew how to do that... but he was not able to interpret it, to transform it into a trend or a problem solving analysis. He wasn't able to really use the information in a well constructed argument. He could not present an argument which was fact-based, by using the numbers and the information that we do collect. …not really understanding what that data means or how it impacts on the business.

Case Study 2

No. of Employees	570
Sector / Sub-sector	Packaging / Plastic food packaging
Region	Yorkshire Forward
Profile of (maths) skills	10 senior managers, 20 middle managers, 40 team leaders and senior engineers, 400 operators (machine operators, packing/warehouse, drivers)
Min. maths qualification	For operators: none asked for, but compulsory numeracy test. For senior engineers, typically looking for a degree with significant maths component
Other qualifications	For senior engineers, relevant degree or degree-level equivalent.
Entry tests	For operators: aptitude tests on numeracy, literacy and quality checking (bought-in from Saville & Holdsworth). For managers/engineers: aptitude tests plus assessment of generic skills (interpersonal, leadership, team role profiling, etc)
Length of time company in operation	30 years on this site
Comment on turnover and perception of skill shortage	Turnover low (slightly higher at higher grades). No specific skills shortages at present: skills development programme for operators to improve literacy, numeracy, IT skills, technical understanding over medium and long-term
Is there training 'on the job' and if so, what?	For operators: on-the-job training for specific jobs Programmes for the development of operators to multi-skilled operators, and MSOs to technicians; all-round development of team leaders and other managers External training in general skills: driving, health & safety, etc

The site visited was the UK plastic packaging factory of a very large multinational packaging company. It produces a product range of several hundred different plastic trays, serving a group of major national and multinational customers. For plastic packaging, there is a major advantage in reducing transportation distances to customers: 'these kind of products are very expensive to transport, they are 95% fresh air; so our company structure is to manufacture close to the market'.

There are two main drivers for the business. First, 'the customer is king', even when it upsets planned production schedules:

> There is a lot of focus on meeting customer expectations on a daily basis. For example, one of our supermarket customers is doing a promotion on poultry. They normally take 70,000 trays a week, but at the moment they want 700,000 of this particular tray per week, that means by tomorrow morning we need 350,000 of these ready to ship, and one of the issues we had to deal with this morning was how to deliver that.

These numbers suggest the volume of the business: factory output is of the order of 5 million items per 24 hours.

Second, there is a huge effort on process control and continuous improvement. The OEE (Overall Equipment Effectiveness) is a generic measure, pioneered by Japanese industry in the 1950s, that can be applied to any manufacturing process:

> OEE considers Availability, Performance and Quality. In a 24-hour period, let's say we expect 20 hours of operation from a machine, so 20 hours would be an Availability of 100%, and our target for that is 100%. Performance is measured in terms of the rate at which the machine is expected to produce, let's say we could produce ideally 100 items per minute, that would be a Performance of 100%, but our target may be only 60%. Quality says, of the items made, how many were of merchantable quality, typically we expect to be at 95% on that. The OEE is then the product of those 3 numbers [*e.g. 1.0 x 0.6 x 0.95 = 0.57 = 57%*], and world-class businesses have a target of 85% OEE. Today in this business we're getting anything from 50% to 85%, depending on which part of the process you look at.

OEE is used as a tool for process monitoring and improvement:

> We're all obsessed with OEE. Here is the plan of what we're going to do this year, going through month by month, so in this particular area we started the year at 71% OEE and we plan to end the year at 80.9%. There is a huge focus on understanding why in any area the OEE is what it is now, and then taking actions to lift it.

Furthermore, OEE information is cascaded down to all levels of the company:

> if you go into the manufacturing areas you will see lots of graphs telling people 'on this shift you were at 75% OEE'. The levels of understanding of that are varied, some people will struggle with percentages and multiplying them together, but we try to visualise as much as possible, nice bright-coloured charts. So, 'don't worry about the numbers, just see if it's going down or going up'.

It is this kind of 'information culture' which drives the aim to have a fully-numerate workforce (see later).

OEE as a methodology can only progress the business so far. There is a need now to go further: 'I think it comes down to survival: today, it's not about taking pounds out of your organisation, but pennies. Without continuous improvement, cost reduction, you're not going to stay around'. A way of going further that the company has adopted is a methodology called Six Sigma (i.e. controlling manufacturing processes so tightly that only 3 products per million will be defective—so there are six standard deviations either side of the mean value within the quality specification limits). Six Sigma is significant in that it includes a training component, with different levels of sophistication for line leaders, technicians and engineers. A major aspect of Six Sigma is to do with *eliminating variability*:

> The whole ethos of manufacturing is to eliminate variability, then you won't have defects and your customers will be happy. When you have poor process control, you have to compensate for it, maybe by increasing the average weight of material in the product [*so the normal distribution lies always*

> *sufficiently above the lower specification limit*], but if you can reduce the sigma, you can use less material and make the product more cheaply. So, all our efforts involve asking 'why is the variability like this?', 'how can we close the gap?'

The people attending the validation meeting informed us that Six Sigma is becoming a widespread improvement methodology in the industry, but that achieving actual 'six sigma' accuracy is beyond many companies because of the inherent variability of the materials they work with.

The drive in the business on process improvement is increasing the need for mathematical skills *at all levels*, for managers:

> The nature of a unit manager's job is becoming increasingly technical. Unit managers have to digest a huge quantity of data every day. I can't imagine appointing someone now without a degree background, they just wouldn't be able to understand what we need.

And for the shop-floor:

> The requirement for mathematics is getting more rigorous. I would not employ anyone today [on the shop-floor] without the ability to do basic calculations, whereas I would have done 10 years ago. We have a numeracy test as a minimum filter, but I expect within the next few years we'll need a more demanding test, because the current one gives us people who won't be able to fulfil the job requirements.

Case Study 3

No. of Employees	50
Sector / Sub-sector	Packaging / Contract packing
Region	South East
Profile of (maths) skills	25 Operators (no qualifications), 4 Line supervisors (time-served, trained in-house) Engineering department (City & Guilds): manager, 3 mechanical engineers, 1 electrical
Min. maths qualification	None
Other qualifications	None specified
Entry tests	None
Length of time company in operation	35 years
Comment on turnover and perception of skill shortage	5 to 10% for operators, much lower for higher-grade staff. Some problems in literacy and numeracy of operators
Is there training 'on the job' and if so, what?	For line supervisors, an in-house induction programme based on bought-in materials: interpersonal skills, leadership skills, teamworking, and dealing with statistical process control.

The company is a 'contract manufacturer and packer': that is, it takes in raw materials and packaging, blends a product and fills it into individual containers, ready for retail sale. The work is a mixture of constant jobs and occasional contracts, which may be one-offs done for just a few weeks. Compared with the highly data-driven culture of the other two case studies, this company showed aspects of somewhat old-fashioned specialisation, in that there is a small number of vastly experienced key staff directing the work of the company.

On the packing lines, there are about 25 unskilled operators, supervised by four line supervisors, who are time-served operators chosen for their ability with the job, and their potential to supervise others. This potential is developed through an induction programme in management skills, and an introduction to statistical process control (SPC). Mathematical skills of line supervisors are an issue, and the SPC work they are required to do is set up with this in mind: 'we have a carefully-constructed system, because they've had no experience of this type of thing since they left school, which may be 15 or 20 years previously …but they do take it on board and become very competent about it'.

There is an engineering department of five people, which deals with machine breakdowns, replacing broken parts, and setting up machines for new functions. These engineers need to be 'completely numerate, to be able to read engineering drawings, that type of thing'. The engineering manager uses CAD software to design new process plant, machinery for specific types of packaging, and new parts for machinery. Increasingly, he is sending CAD information electronically to manufacturers for input into computer-based manufacturing machines. The company's electrical systems manager designs and writes all of the PLC (programmable logic controller) software for the process and packaging machinery.

The company uses SPC to monitor and improve its processes, but it is not used to such a sophisticated degree as in the other case studies. All data is collected manually for entry into the company's computer system, but there is no reporting back of numerical performance information to the shop-floor, as in CS2. Line supervisors take samples according to a precise schedule: examining, weighing, checking against various tolerances, and recording the findings on a control sheet. There are control limits on the weight for each product (beyond which products are 'defective'), and warning limits, which alert the supervisor to possibly stop the line, and call in help from an engineer. The trends that supervisors have to spot are generally clear: 'Unless there's a failure in the filling machine, they will not see any great deviation; when they do see it, they have orders to stop the machine and call for assistance.'

Higher-level SPC work, analysing data, and establishing control limits for machines, is handled by the quality control department, which oversees quality issues throughout the factory.

The company management expressed some concern about the numeracy and literacy of the unskilled operators:

> The basic 'three Rs' really. We don't require them to do any maths, except to count items on the factory floor. It's a problem we've seen for some years now …. When we have someone who is numerate, we utilise their skills as much as possible, putting them where they're most useful to us.

Given more time and resources, the company would like to do something about numeracy: 'A lot of people are frightened of numbers, and I think if we suggested to some operators that they should learn more about numbers, they would not be keen to do it.' For now, there are no plans to do numeracy testing in the selection of operators, though line supervisors can get support to develop mathematics skills.

Pharmaceuticals

Case Study 1

No. of Employees	30
Sector / Sub-sector	Pharmaceuticals / Manufacturing
Region	East of England
Profile of (maths) skills	R&D Sales and marketing, management accountant Site Admin Technical services (training, purchasing) Quality Control Manufacturing operations 4 directors, 12 key people. All graduates except lab supervisor.
Min. maths qualification	All except 5 lab operators in manufacturing have degrees or A level +
Other qualifications	Changing skills at huge rate
Entry tests	No
Length of time company in operation	Founded 1984. Amalgamation 1997
Comment on turnover and perception of skill shortage	Turnover low (stable population) but foresee a shortage in IT skills; training on the job/observation is underway, recruiting young people with IT skills
Is there training 'on the job' and if so, what?	Nothing formal. Huge need for IT skills.

The company is involved in the development, manufacture and marketing of medical diagnostic kits and reagents, to be used largely in developing countries. The company is research-led, with the aim of developing novel technologies for diagnostic products appropriate for use in developing countries, i.e. simple technology, no expensive equipment or complicated techniques that require special training. The case study took place in the manufacturing side, focusing on the eight people involved in the production process, who fill the bottles, fill in and stick on labels, put bottles in boxes, and their manager, whose job is to ensure quality control processes are followed.

Most of the manufacturing is relatively simple mixing and blending, but everything has to be very tightly controlled from a quality control point of view. There are clearly-defined work instructions for every single activity, detailed records of how they put together the products, checks on what comes in and checks that the product actually does what it's supposed to do. This approach is quite recent and is a huge change from past practice. It was brought in to meet the standards of a European Union directive on the manufacture of diagnostic materials. It is a very disciplined regime and there has been quite a transformation over the last two years. The requirements of jobs – the qualifications needed for a particular role – are changing as an essential part of defining the quality assurance process. There is also currently a widescale process of computerisation to collect data to monitor performance.

A new set of disciplines are being learnt and the company has yet to define the needs and appropriate qualifications. In the past people recruited as ‘friends of friends’, producing a stable work force with recruits coming from the local community. The sort of competencies required are now a very disciplined approach and systematic attention to detail. Installing the new process has been difficult given there are older people who have been in the job for a long time and know the production side (without the skills in quality control monitoring or IT) and young people who need training in possibly both areas.

The main intermediate mathematics skills identified (and the associated skills problems) involved the production workers’ understandings of *concentration* and *variability*. All the concentration calculations in the process are pre-calculated in look-up charts to bypass any need for calculation, which will produce error. Also, all critical operations are checked as it was argued that production workers have no ‘feel’ for concentration. Production workers are felt not to understand the inevitable errors or variability in their measurements, and the need to have reliable and acceptable limits on the variations. They should be able to spot trends and notice general bias in their measures.

Case Study 2

No. of Employees	110
Sector / Sub-sector	Pharmaceuticals / Research & Development
Region	East of England
Profile of (maths) skills	10 PhDs, 70 graduates, 30 technicians (various qualifications: HND, ONC, BTEC). Pharmacists, Chemists, Engineers.
Min. maths qualification	None is specified (though useful/desirable for both technicians and graduates to have A level maths)
Other qualifications	For technicians, the main requirement is for practical skills, and a knowledge of chemistry
Entry tests	Yes, but only for industrial placement students, on practical laboratory procedures
Length of time company in operation	About 100 years
Comment on turnover and perception of skill shortage	Very low turnover of technician staff. Students (both FE and HE) don't get a good feel of what practical work is actually like from their courses
Is there training 'on the job' and if so, what?	Yes, for specific technical skills related to the work, and general soft skills (e.g. writing, presenting).Training courses are given in statistics, and other aspects of mathematics are dealt with via individual coaching where difficulties arise.

The laboratory visited is one part of the development arm of a large pharmaceuticals development and manufacturing company. The case study looked at one of the lab's tasks, which is to determine the stability and 'shelf life' of new drug formulations under the range of typical storage conditions that might be experienced in different regions of the world. This involves storing a drug in temperature and humidity-controlled rooms for periods of between 6 months and 2 years, and at monthly intervals taking out a sample of the drug for analysis in terms of amounts of active ingredient and impurities.

Most technician staff are expected to be able to deal with data in spreadsheets and similar software. All the work of the lab is about creating and analysing data, in particular in assessing stability the analysis involves looking for trends in data.

One example use of graphical representations is 'time-point analyses', where a sample is analysed initially, then again at 3 months, 6 months, 9 months, 12 months and beyond. Routinely each time a new time-point is found (by chemical analysis), a graph is drawn of the data, and technicians are expected to be able to interpret those graphs and pick out possible anomalies, making use of a range of statistical tests built into the spreadsheet software (as macros), which can determine trends in routine cases. This work is supervised by graduate-trained staff who will take final decisions (the workload is divided up across teams, each of which has an experienced team leader, graduates and technicians).

Although intermediate mathematics skills are necessary for all the lab's work, there is no minimum mathematics qualification demanded for recruitment. Rather, it is the balance of skills and experience that counts, with chemistry as the main component. Even for graduate staff, having A level mathematics was less important than the knowledge and skills gained at university. The biggest 'headache' in terms of 'missing' skills in new recruits (both graduate and non-graduate) was about practical chemistry:

> Generally we'll complain that people don't come out of academic institutions with the correct practical, technical training, so they'll have done a lot of theory but the amount of equipment and the quality of equipment available in most academic institutions is so poor that the students don't get a good feel of what practical work is actually like. So we have to end up training them quite a lot ourselves.

Problems with mathematics are experienced, in terms of doing concentration and dilution calculations, but not to such a degree that formal training has needed to be implemented. Individual coaching, and the natural tendency for less mathematically-able employees to remain in those posts where less mathematical initiative is required, are proving to be adequate solutions.

Example: Statistical analysis of experimental data

The laboratory staff can call on the expertise of a specialist in 'chemometrics', that is, the application of mathematical techniques to chemical experiments. The specialist commented on problems in appreciating the limitations of statistical analysis:

> If you are interested in looking at how best to produce a formulation of a new drug, there are number of ways to do that, if it's a tablet then you have the drug combined with excipients, inert materials, that serve some sort of purpose, perhaps to aid the release of the drug. When you manufacture the tablet, the amounts of excipients, and the physical form of the tablet, can all be considered as variables, so experimental design uses a structured, mathematically-based approach to designing that series of experiments. You collect the data that you're interested in, typically an assay value, that is how much drug has been made into the tablet, and then analyse the data collected using something like linear regression. I do that analysis, to see which factors are important, which variables, say one of the excipients is lactose, does the amount of lactose in the formulation affect the rate at which the tablet dissolves. One of the interesting things for me in that kind of analysis is that there is very little consideration about how that data has been calculated, how it looks based on very simple mathematical measures, say if you do the same procedure five times, are the five results very tight together, or are they diverse. It's all about accuracy and precision in the way people think. That's the part of the process which I think is routinely badly done. What would you call it — the initial survey of the quality of the data that's been collected. The issue I routinely come across is where people accept a calculated value without thinking how it was calculated, what other things are there to consider about the value.

Another example of this occurs in dealing with outliers in data sets:

> If you have a series of ten numbers, and you're aiming for a value of 10, so you have 10.1, 9.9 etc and then one of them is 8.3, you would say that one is

different to the rest. Is it genuinely a statistical outlier? There are tests you can do, but quite often I come across people who say, ‘it’s an outlier therefore I will delete it’, after all 9 data points are not much different from 10, and the result is probably good enough. In some situations that’s acceptable, say when you’re doing research and looking for a general direction. But if that low reading has come about by a particular set of circumstances, which by data review you could pinpoint, that low reading could be the most valuable part of the data generated. Excel allows you to do outlier tests, and if it’s an outlier it’s often deleted. I think the general principle is having an understanding of what you’re trying to achieve using mathematical tools, which are not magical tools, but they can provide you information.

Case Study 3

No. of Employees	35
Sector	Pharmaceuticals/Start-up
Region	South East
Profile of (maths) skills	Technicians: NDs and HNDs Graduate Research Assistants and Scientists (postgraduate qualifications) - all in Science, not Maths
Min. maths qualification	All have done maths post-GCSE (even if no formal qualification) except for secretarial staff
Other qualifications	See above
Entry tests	No
Length of time company in operation	3 years
Comment on turnover and perception of skill shortage	Low/none - as yet
Is there training 'on the job' and if so, what?	Technicians sent on courses

This is a bio-technology spin off company consisting of a small team of scientists with PhDs, and technicians. Technicians are core members of the team, they need to understand the nature of the experiments, the equipment and the software, and are responsible for database construction and archiving as well as running equipment, taking and recording measurements. There have been two waves of recruitment, done informally now as the company is small; this will need to be formalised later when more staff are needed.

The current phase of work is research and development and piloting of production. Most of the work concerns clinical trialling of new treatments and analysis of data. Mathematics is all pervasive: 'We had a couple of situations where there were clear algebraic errors – if gone unchecked, we would have had really wrong results.'

The work involves the measurement of huge amounts of data:

> We are dealing with a phenomenal amount of data. Suppose we're using a marker for white cells and we want the machine to count 10,000 of those — well that could be maybe one in 12, meaning 120,000 events… Now, we stain each individual's samples with 7 different combinations. Each individual comes back every two weeks. We are looking at 30 individuals and running it for two years. That is a frightening amount of data.

The data have been used to 'discover things that we didn't expect to see'.

Strict quality control procedures are essential in this context: 'we can't afford mistakes'. The most important thing is monitoring measurements and spotting errors. There have been difficulties with employees knowing what is a bad measurement and avoiding systematic error; and with understanding and using proportionality (in dilutions) and logarithms.

Tourism

Case Study 1

No. of Employees	60-70
Sector / Sub-sector	Tourism / Medium-size resort hotel (60 rooms)
Region	East of England
Profile of maths skills	No explicit maths skills except owner (accountancy background). 8 departments: reception, porters, housekeeper, restaurant manager, kitchen, bar, administration. 3 duty managers have degrees in hotel management. There is one general manager.
Min. maths qualification	None
Other qualifications	People skills, common sense
Entry tests	No
Length of time company in operation	Approximately 75 years
Comment on turnover and perception of skill shortage	Very little except in operational side. Shortage of chefs, and growing need on reception for hybrid personal/communication.
Is there training 'on the job' and if so, what?	Only informally, e.g. head chef started as junior 20 years ago.

There was very little evidence of intermediate mathematical skills of any sort. Suggested reasons are:

- it is a privately run hotel with all decisions largely made by owner. There is rather more space for initiative recently as stable business patterns of the past are changing;
- it has a stable and loyal client/guest base: importance of relationships with guests is paramount, although there is a need to juggle rooms to maximise availability;
- it will never overbook;
- there has been little computerisation in the past (except in accounts) but with recent appointment of new General Manager there may be an increase in accountability to owner with more need for computerised data on stock and planning projections, trends, estimates; and
- there are few staff shortages (except on operational side, particularly chefs) as little competition in the location, but there is a growing need for staff in reception who can combine computer skills (largely accuracy, systematic data entry and checking) with good face-to-face client skills. Room bookings are not automated

and a manual chart is used as there is a need to maintain personal contact (i.e. matching the very different rooms to guests' needs).

The chef's work proved a good example of how craft 'know how' was used to reach target of 65% profit on a meal of £25. He had to balance knowledge of food in season, cheap/expensive ingredients, and skills profiles of the 10 staff in kitchen. For example, a decision had to be taken whether to take the time to make pastry in the kitchen or to pay for delivery from nearest shop which is many miles away. NB. This is not modelled, just judgement in the moment.

Case Study 2

No. of Employees	Over 500
Sector / Sub-sector	Tourism / Large city-centre conference hotel
Region	South-east England
Profile of (maths) skills	Accountancy staff are located off-site at group head office Very varied profile: from HNDs and management degrees with mathematical content to many staff with no formal qualifications
Min. maths qualification	None
Other qualifications	Managers traditionally have BTEC diplomas or HNDs; but recently a preference for A levels/degrees plus on-the-job training
Entry tests	Specialised tests for managers (developed for the industry by a US company and widely used by hotel groups)
Length of time company in operation	Over 100 years; bought by its current parent group 5 years ago
Comment on turnover and perception of skill shortage	Very high turnover. Acute skills shortages
Is there training 'on the job' and if so, what?	Yes: staff sent on industry-specific courses

This is a large 400-bedroom hotel in a busy city centre, with a substantial conference business (comprising about 35% of overall revenue).

Bedrooms and conferencing operate as distinct operations. The multiple rates for bedrooms are set by the specialised manager (and his team) responsible, and are modified constantly. All rates are stored in a computer database, and reservation agents on the phone (plus travel agents and licensed independent booking offices) will quote from the rates which the computer displays.

> They take in details of dates and number of people, and the computer brings up rates for them, they don't have to think about it … you've probably got 300 – 400 different rates, say for different companies who are regular clients, or if a travel agent phones up we quote them from the leisure rates or the special offer rates. It's the job of the Manager to open and close the rates, if he thinks we're going to be busy in a certain period he'll close off the cheap rates, and when the agent types in that date only expensive rates will come up. … There are five or six rates set by the computer, and they've got to judge how much the person is likely to pay.

In contrast, the agents who deal with conference bookings have a free rein to negotiate downwards from pre-set maximum rates.

Example: Negotiating a conference booking

You can sell bedrooms all the time, but if you're not good at selling conference space then you won't sell it. Yes, you've got the top rates, but every day is different, it's very complicated to work out what rate to quote. First, you've got to think what will the company pay, is it a government body, or a corporate? How much do they have to spend? Then, how many people is it, does it fit in with what I want. 100 people would be good, but my room can take 200, so do I leave it or quote quite high because of the lower numbers? You think about what day of the week it is, Mondays and Fridays are quiet, Tuesdays are a bit busier, Wednesdays the busiest. Is it 2 or 3 days, say a Monday–Tuesday would be a good booking. A Wednesday on its own would not be, because if you sell that Wednesday you've blocked out someone who wants to book 3 days. There's a lot to think about. We'll ask them, do you have a budget, and they might say £—, so you know that's all they going to spend and if they can go somewhere that fits I would say 'OK, we'll do it for that'.

We also charge on the basis of a per person 'day delegate' rate, which includes room hire, refreshments and lunch, and basic equipment. Other equipment we'll charge for separately. There is a set maximum rate which is £95, and also a lowest rate, nothing official, not printed on black and white. Generally people will quote 85 and upwards, 89, 95, sometimes they'll go down to 77. There are only certain rates that we quote, I mean nobody quotes 81 or 83, I don't know why, it's just normally, 80, 82, 85, 89, 90, 92, 95.

I'm a senior person in the office, so people will ask me, 'would you take this booking', based on how many people, the day and the date, I'll quickly grab a calculator and work out the total revenue, how much room hire I'm going to get out of the day delegate rate they're quoting, how much for teas and coffees, how much for lunch, I'd quickly work out.

Interviewer: Suppose you're on the phone and you're got to think fast, you don't always have the time to go to the calculator?

When you're on the phone you don't necessarily need to work out a total figure, because you know roughly, it's 200 people times £85, rather than 82, 89, whatever. You're not thinking 'what is that total?', you're thinking with the broken-down figures.

Interviewer: Because the numbers are familiar, 200 times 85. They're the numbers you work with all the time?

Yes, you know it roughly, but not exactly to the pound.

Case Study 3

No. of Employees	About 30 (some part-time/voluntary)
Sector / Sub-sector	Tourism/Wildlife reserve and visitor centre
Region	South East England
Profile of (maths) skills	Centre manager; general administrator, events administrator; retail staff (manager and retail team); catering manager, with (highly-experienced) chef and staff; ground and reserve wardens; ground and building maintenance; marketing officer; ecologist; environmental educationalists. (Management/admin staff have mainly degree backgrounds)
Min. maths qualification	None
Other qualifications	Experience (perhaps as a volunteer) in a wildlife centre
Entry tests	No
Length of time company in operation	3 years on this site; part of a 50 year old national organisation
Comment on turnover and perception of skill shortage	None reported
Is there training 'on the job' and if so, what?	None reported

The site visited is one of a network of wildlife reserves operated by a national wildlife conservation trust. There are issues to do with balancing visitor numbers (and the admission fees they pay) against the disturbance they cause to the wildlife on the site. This site is quite new, a couple of years old, and a limit on visitor numbers (300,000 per year) has been set based on previous experience at other centres (the first of which opened 50 years ago, so the background experience is substantial). Visitor numbers are currently only 200,000 per year, so nowhere near yet the tolerable limit, and the balance between visitors and wildlife is going very smoothly.

Mathematics-related work on the site is principally concerned with scientific tasks - monitoring the diversity and numbers of different species present (a lot of data is required, not only for the centre's and trust's own benefit, but to report to the national regulatory body which grants the site protected planning status only if wildlife diversity can be continuously demonstrated). Excel spreadsheets are used in many aspects of the centre's administration, and staff are expected to be comfortable with constructing and manipulating spreadsheets.

The staff is small, and mainly graduate-trained (except for more generic retail and catering jobs). People tend to be recruited because they are enthusiasts for the work of the trust, and having some background in a particular area (marketing, education, etc.). People's degrees are not necessarily in a 'relevant' subject: it is most usual for new recruits to have done substantial (several years at least) voluntary work for the trust at one or other of its centres, thus giving them the appropriate training for the work of the centre.

Appendix: Instruments used in research

Telephone Interview Schedule

The aim of this telephone interview is to obtain:

- a broad picture of the work,
- the range and profile of the employees in terms of skills, expertise etc.

We anticipate that in a smallish company the Technical Manager might be a good contact, or a person having an overview of the company and jobs within it and who has access to company data, for example, the personnel officer.

The telephone interview will need to identify someone (or a few people) for observation and interview on the subsequent site visit. Once identified, we will need during the telephone interview to obtain some information on what the identified person does, their job title, what their work involves, where they fit into the company structure.

Outline questions for telephone interview

1. For which jobs/roles within the company do you either require or strongly prefer candidates with intermediate maths skills of this type. Give examples of skills:

   Use measures
   Convert between measures
   Use formulae
   Work out dimensions from scale drawings
   Use 2D shapes or 2D representations of 3D shapes
   Collect, record or read data from graphs and charts
   Use percentages and ratios
   Understand average and spread
   Read scatter graphs

2. Approximately how many employees are engaged in each of these job areas?

3. Do you either require or prefer particular formal qualifications for these jobs specifically, or for employment in general? If so, do these include:

   GCSE Maths grade C or above
   GCSE Maths (any grade)
   O level maths
   BTEC Diplomas (of particular type)
   City and Guilds qualifications (check on whether want specific ones)
   RSA qualifications (check on whether want specific ones)
   HNDs (check on whether want specific ones)
   Other

   If maths qualifications are required/strongly preferred:

Are there ever exceptions to this? e.g. would you appoint someone who does not have any maths qualifications to the posts you identified in question 1?

Under what circumstances / criteria would you do so?

If no requirement for qualification, probe:

Would it help at all at shortlisting or interview stage if a candidate had any of these qualifications, even though they are not necessary?

4. If particular qualifications are required:

   Do you ask for particular grades or units (e.g. advanced BTEC maths units) in any of these qualifications?

   Is a mathematical qualification a priority or do other factors ever/generally take precedence? what factors?

5. So far, I have asked about maths qualifications or qualifications with a technical or maths component. More generally, do you stipulate that candidates should have a general level of education for the jobs we have been discussing? For example, so many GCSEs/A Levels/degrees?

6. Does the company administer tests directly to applicants? If so, do you use any of these? If yes, are any of them important, or even crucial?

   Quantitative or numerical reasoning tests
   Numeracy tests
   Mathematics tests
   Specific skill (e.g. spatial) tests

7. If yes to 6: When were tests introduced? Was this in response to problems with existing workers? Or changes in job requirements?

8. If answered 'Yes' to question 7: - What is your opinion as to why this is the case?

On-site guidelines for observation and interview

We will seek information around the following questions which will be couched in the discourse of the employment in order to identify if the skills are needed in some form (e.g. discount, stock control, odds). The 'you' will be person who has been identified by the telephone interview as 'using' maths skills. *As much as possible, we will try to extract and feed in examples to clarify what we are doing. Maybe collect documents from workplace, in house video etc.*

1. What mathematical skills are needed in your occupation or in your job in general? For example:

(a) Do you use any of the skills below?
- use measures
- convert between measures
- use formulae
- work out dimensions from scale drawings
- use 2D shapes or 2D representations of 3D shapes
- collect, record or read data from graphs and charts
- use percentages and ratios
- understand average and spread
- read scatter graphs

(b) Are you required to extract, interpret and communicate information or identify patterns, isolate information or trends based on mathematical judgements?
- identify the main variables in a situation and have an idea how they interrelate
- identify and appreciate risk factors and confidence limits
- communicate and justify what they do
- use approximations and estimates to corroborate and confirm results
- appreciate variability but also trend

(c) Are you expected to display mathematical problem solving skills?
- appreciate links between disparate data sources or representation and base decisions on structures, models or logical analysis alongside immediate concerns
- generalise or choose between representations
- communicate links/relationships between variables to others, including consequences of changes in one variable for others

(d) Are people expected to display computer skills (needs clarification e.g. Excel skills?)
- use computer to calculate, represent information or check results or trends
- understand file systems and communication procedures
- set up or modify spreadsheets or databases

For each of the skills mentioned try to find a *specific example* of when this skill was needed and why it was needed. Obtain as much detail as possible about the context, what else was going on, were other people involved etc.

2. Ask for a description in as much detail as possible of an occasion when something *critical* happened, something did not work out etc, and when you (or another) had to use some mathematical skills to resolve the problem.

3. Ask for a description in as much detail as possible of an occasion when something *critical* happened and you were aware that mathematical skills might have helped to resolve the problem but for some reason mathematical skills were not used.

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