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Alternative strategies for the development of mathematical thinking amongst undergraduate business studies students within the context of Operations Management

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Background and rationale

Introduction to Management Methods and Techniques (PT 2003) is a second level core module on business awards at the university. Cohort sizes are approximately 100 in semester one and 250 in semester 2. The syllabus is essentially an introduction to the theory and concepts of operations management, including some basic quantitative techniques for the measurement, analysis, evaluation and improvement of work systems. Until recently, the teaching and learning had taken place using traditional strategies relying heavily on weekly lectures and 'expert' demonstration of techniques, to classes of between 40 and 100 students who would quietly copy the overhead slides. At the end of each lecture the tutor would hand out exercises for students to do individually in the tutorial sessions that followed, however, very few students would attend.

The assessment regime for many years had been 50% by coursework assignment (mid-semester) and 50% by a 'closed-book' unseen end-of-semester examination. Both assessments required the student to acquire, reproduce and discuss theory and techniques, however, the marking scheme was biased in favour of accurate performance of appropriate techniques. Exam results were always disappointing.

The combination of content-laden syllabus, traditional teaching methods and assessments that test memory rather than understanding, is likely to produce negative perceptions of the subject. Many studies show that this approach often leads to surface, strategic and/or avoidance behaviour amongst students (see Marton & Saljo, 1977; Brandau, 1990; Crawford et al. 1994; Crawford et al. 1998; Prosser & Trigwell, 1999). I was not surprised therefore to see evidence of these surface learning strategies amongst the PT2003 students that I observed.

The teaching of quantitative methods for planning and controlling resources, decision making, measuring and improving quality is well established in business schools world wide. However, Naude et al. (1997), in their survey of over 1200 managers from the UK, New Zealand and South Africa, found that managers held similar beliefs about the usefulness of the techniques they had been taught in the real world:

Among the non-users of statistics, the most consistent reasons given in all three countries were either that the techniques were regarded as being irrelevant or inappropriate in the particular work environment, or else that the techniques were not warranted/needed/required. (Naude, et al. p.223).

Furthermore, they found that many of those who used quantitative techniques regularly in their work would rely on one or two familiar techniques and apply these to all sorts of problems and situations even when others would be much more appropriate. This suggests that the typical technique-led module encourages students to focus on techniques for solving problems rather than developing their understanding and analysis of problems.

Managers need to make sense of the situation or problem with all its uncertainty and complexity before they can decide how they are going to solve it and with which quantitative tool or technique, if any. Making sense of the situation requires much deeper thinking than simply selecting the right mathematical technique. It does, in my opinion, require mathematical thinking, a dynamic process involving specialising, generalising, conjecturing and convincing that leads to greater *understanding* and which may lead to the search for alternative quantitative techniques, adaptation of existing techniques or the development of new ones. Mason et al. (1995) maintain that mathematical thinking encourages us to attack problems and blockages by drawing upon what we already know, being clear about what we want and introducing new ideas or information that can shed light on the problem. Getting stuck is part of the process and the point at which we need to review where we have got to and reflect on how we got there. Making a breakthrough usually comes after a period of checking, reflecting, mulling, conjecturing, extending, justifying, etc. Once learned, mathematical thinking becomes a powerful process for

tackling any problem or question and, I would argue, more valuable to students and managers than a list of formulae and instructions for solving abstract problems.

It is my view that the business schools should be moving away from teaching techniques to developing students' mathematical thinking. In this report I describe how I attempted to initiate this and other changes within the context of an undergraduate operations management module and evaluate the effects of the changes on students' mathematical thinking.

The innovation

All new or modified modules are subject to the approval of the School Quality Committee but, apart from this quality control measure, module teams are generally free to determine the module syllabus, pedagogy and assessment. We chose the assessment as our starting point for change to PT2003 but, because a change to one aspect of the curriculum will impact on another, we found that our method of module re development was not linear. We played around with different ideas, piloting some of these with current groups of students before finally arriving at the synergy we wanted between the three aspects of the module. That said the following account appears as though the process were straightforward. It was not.

Assessment

The two forms of assessment for the original module provided neither timely nor meaningful feedback to students on an individual basis. There were no marking criteria available for either assessment, and, as mentioned above, neither assessment tested the intended learning outcomes. The original assessment regime was therefore unreliable, invalid and meaningless to students.

The changes we proposed were to:

- a. write a set of clearly articulated marking criteria and performance descriptions that matched the module leader's intended learning outcomes
- b. get rid of the group assignment to reduce the emphasis on summative assessment
- c. re-write the exam paper to provide opportunity for students to demonstrate depth of analysis and reflection, critical evaluation of quantitative tools and techniques and selection and application of theory with justification. This would now be 100% open file examination. Students would be encouraged to support their exam answers with evidence from their coursework
- d. introduce into each classroom session structured formative assessment and feedback opportunities, using self-, peer- and tutor negotiated feedback criteria

Syllabus

We wanted to provide time in class for students to discuss operations management topics and issues in depth but the original content heavy syllabus would not allow time for this. We therefore decided to reduce the content by removing topics that we felt could be addressed more deeply in follow-on modules or which, on reflection, were inappropriate for the module objectives.

Originally the module leader had chosen the topics about which he believed students ought to know and which he sequenced according to his own view of the subject. He felt in control of the subject and of the teaching and could justify this teacher-focused approach in terms of structuralist theory, i.e. that the syllabus should reflect the structure of the subject. (See Vithal et al., 1995, p.217). However, the pilot sessions revealed that the students had not internalised the theory nor seemed to have developed the mental map of the subject that had been presented.

A student-focused, flexible, open-ended syllabus would allow students to construct their own maps of the subject. They could pursue a particular line of enquiry, explore more deeply related topics that interested them, move on to topics sooner or later than planned. In order to do this, we introduced projects and subject focus groups where students could specialise in a particular a topic from the syllabus and carry out their own independent investigations within that field. These project and focus group investigations would be going on along side the more conventional 'taught' syllabus.

Pedagogy

In order to realise the changes to the syllabus and assessment, we had to make radical changes to the traditional methods of teaching originally used. There would be more time for in-class activities, discussion and feedback, more use of small group and inter group work followed by whole group sharing. There would also be class time set aside for project work, focus groups and progress reviews. Tutors would act as facilitators, fielding questions, identifying misconceptions, encouraging students to question and challenge each other's views, summarising key points. There would be only one or two 'formal' lectures.

Group work would be structured around some operations management issue, problem or task and sometimes this would take the form of a simulation and/or role play. (See Schniederjans, 1993: 289–301; and Kolb et al, 1991: 514–527). For example, in one three-hour session, students are asked to design and implement the process type and layout of resources and materials for the most efficient production of goods (or delivery of service) for one of three different companies. Each group then implements its layout and process design using the raw materials, equipment and furniture provided e.g. three pin plug components. Students are required to test the efficiency of their operation during and after production (or service) in terms of speed, productivity, quality, job satisfaction, etc. and to make modifications for improvement. Following a brief period of review, re design and re testing, each group is encouraged to record, analyse and evaluate their design choices, data, methods and techniques, problems they encountered and so on. A plenary session then allows groups to share experiences, reflections, etc. with the whole group whilst the tutor notes key issues and points on the white board. This *harvest* of personal knowledge is interpreted for the public domain and matched against its social representation i.e. theory. (See Edwards & Brunton, 1992). In this way the formal theoretical points are 'covered' but the students have more control over how and when they get to them. Students enjoy the simulations, can physically see the difficulties associated with real world problems, can extract the mathematical concepts from the experience and engage in mathematical thinking. (See Appendix 1a and 1b. Photographs of students engaged in various simulation activities).

The Student Case Study Project was another strategy we used to realise the aims of the new syllabus and assessment. The idea here was that students would form small groups, select three operations management problems or activities, such as inventory management, capacity planning and resource management, and find out how real companies deal with these issues, what techniques they use, etc. They then compare and contrast their findings to the theory presented in the literature. Thus students have to carry out secondary as well as primary research. Throughout the project students present interim findings to the whole class and make a final presentation at the end of the module both orally and as a written case study.

The project allows students to make choices, specialise and encourage the development of project and time management skills. Students are given the project brief and an overview of the basic concepts of project management in week 2 so that they have the remaining 10 weeks to plan and carry out activities, allocate resources and complete the research. Rather than simply copying the lecturer's construction of a simple project network diagram and Gantt chart, now students create their *own* charts and diagrams for their *own, real* projects using industry-standard Project Management software.

Sessions at weeks 5, 8 and 11 are set aside as 'milestone' sessions for monitoring and reviewing progress. Students to mark off their progress on their Gantt charts and produce Progress Reports listing problems encountered, solutions, etc. These sessions also provide the opportunity for students to share their research findings, teach each other, seek advice and get feedback. (See Appendix 2. Photographs of a Subject Focus and Project Review sessions). The process of project management and the product of the process, i.e. the case study report and presentation, are peer-assessed against student-defined criteria in week 12. The students' evaluation and reflection on both aspects of the project are formally assessed in the examination.

Evaluation

Methods of data collection

We video-recorded the weekly class room sessions and set aside an afternoon each week to review and evaluate these, making further adjustments to the up coming sessions as needed. Following a review of the whole module in Semester 1, we made a number of further modifications which we tested and video recorded again in Semester 2 using three new groups.

In addition to video and audio data, we also interviewed and surveyed students on their views about learning mathematics and how the new module had changed them. We also collected group posters, individual in-class pieces of reflective writing and examination scripts as additional data sources.

Analysis of the data

The main research question was: *are the alternative teaching and learning strategies and methods effective in improving the quality of student learning generally and developing mathematical thinking specifically?* I therefore noted the quality and type of mathematical thinking observed and the activities that provoked this. For example, 'questioning' behaviour (where the student poses questions for subject investigation, queries assumptions or clarifies ambiguity) would be categorised as deep learning behaviour and high level mathematical thinking. Alternatively, 'giving up' behaviour (where the student makes little or no attempt to check back to identify the cause of the blockage before either calling for teacher or giving up completely) would be categorised as surface learning behaviour and low level mathematical thinking.

To ensure thorough analysis of the data, I set up the categories of analysis using NUD*IST (Non numerical Unstructured Data Indexing Searching and Theory-building) software and imported fully transcribed video and audio recordings plus field and review notes. I then applied the categories to these data and ran a series of reports to show in particular which activities provoked deep learning, high level mathematical thinking and which produced the opposite effect.

Early findings

It has still not been possible to complete the full analysis of the data because of the time it has taken to transcribe verbatim all the video and audio tapes. However, interim findings suggest that the teaching and learning activities provided the opportunity for students to think more deeply and engage in mathematical thinking and although many students took this opportunity there was still the tendency amongst some students to give up without really trying or to sit waiting to be told what to do.

Evidence from the project work suggested that students had developed a healthy scepticism of the management theory and techniques presented in text books. Applying these concepts to their own places of work meant that the subject matter was more meaningful and relevant. Nevertheless, there were still a number of students who admitted that because the project was not assessed formally until the examination they did not put in as much effort as they should have in presenting and compiling the report. They argued that other formally assignments were due around the same time as the project completion and that they considered the PT2003 project work as a lower priority. In the examination those who admitted taking a strategic approach to their project work also expressed regret at doing so.

Many students commented on the simulation activities in particular saying, for example, that they:

'... enabled me to see the process working and physically see where problems were occurring'

Others found the role play activities:

'...made it easier to understand the different issues that effect job design from both the workers and managers point of view'

Most students agreed that the opportunity to discuss their ideas with each other helped enormously:

'(Discussion) helps reinforce learned material seeing others presenting same findings and areas missed'

'Discussion was brilliant and I went away from lectures piecing the information together and thinking on things I could have added to the input of the lecture'.

The question sheets accompanying the classroom activities did prompt students to look for mathematical concepts in the activities they were immersed in (see Appendix 1 for example) but few looked deeply. This was a little disappointing but perhaps unreasonable since it was not our objective to turn students into mathematicians but to raise their awareness of importance of quantitative methods in management to be able to interpret and challenge statistical data and to be confident in asking questions of statisticians. We felt that many students could do this without necessarily being competent in 'doing the sums'.

Classroom discussions also revealed that students had begun to make judgements about the validity and reliability of management decisions whether or not quantitative techniques had been used. We were also

encouraged that students had been able to transfer this learning to work or other personal situations. It seemed therefore that our methods had been effective in achieving deeper understanding as the following quotations suggest:

'I really knew I understood ABC/Pareto analysis when I used it in another module...'

'I really knew I understood SPC's (statistical process control) when I realised that you can substitute technical jargon for normal terms...'

'I really knew I understood EOQ (Economic Order Quantity) when I discussed it with other students studying inventory management, formulating a worked example and presenting our ideas'

Probably the most disappointing outcome was the lack of improvement in examination performance. We marked over 200 examination scripts in semester 2 and found that students reverted back to describing rather than analysing, reflecting, conjecturing and evaluating. Students did not support their arguments well nor present alternative perspectives even though they had access to their file notes and could have prepared much of the material in advance.

The level of critical thinking amongst some students during classroom discussions may have raised our expectations that all students would produce well-articulated written arguments in the exam. Perhaps this was a little naïve although it seems to be the case that business students are more adept at oral rather than written communication perhaps because they receive more regular feedback on their presentation skills than on their writing skills. Most individual writing assignments are assessed at the end of the module when the feedback to students is too late for students to make use of it. Mid-term individually written assignments rarely contain sufficient meaningful feedback to help students improve and, in an attempt to reduce the marking load, many modules are assessed by less time consuming methods such as multiple choice tests. Some of these methods require few, if any, writing skills.

We also have to consider that our expectations of what students should do to achieve the higher grades may have been unrealistic particularly under examination conditions. It is comparatively easy to memorise formulae, perform calculations and describe theory. It is much more difficult to interpret data and discuss the implications or alternatives within a messy situation (see Appendix 3 Assessment criteria and performance descriptors).

Lastly, I feel we may have underestimated the amount of time it would take to reverse the life long belief amongst many students (and some teachers) that examinations are about reproducing notes. In spite of 'coaching' to the contrary, many students, I believe, reverted to descriptive writing and 'doing sums' rather than writing critically about the project, problem, technique or theory.

Further developments

As with any innovation, there is always room for improvement and we have identified a number of minor changes. We do feel that the approach we adopted and the changes we made have made a qualitative difference to some students but that this approach has to be adopted at Level One and across all subject areas if there is to be a widespread change in students' approach to learning. We are encouraged by the response we have received from colleagues within the Business School and externally. Colleagues in other subject areas have already expressed interest in our innovation and have approached us for advice and guidance with the view to adopting alternative approaches to their teaching. We therefore intend to follow up this interest by setting up individual and group sessions in which we can share our experiences and help others develop good practice.

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Appendix 1a: Simulation



The Re-Fuse Plug Company

This group of students has decided that as the product they are making (3 pin plugs) is very simple to assemble and is required in large volumes, the most appropriate manufacturing type is LINE or MASS production.

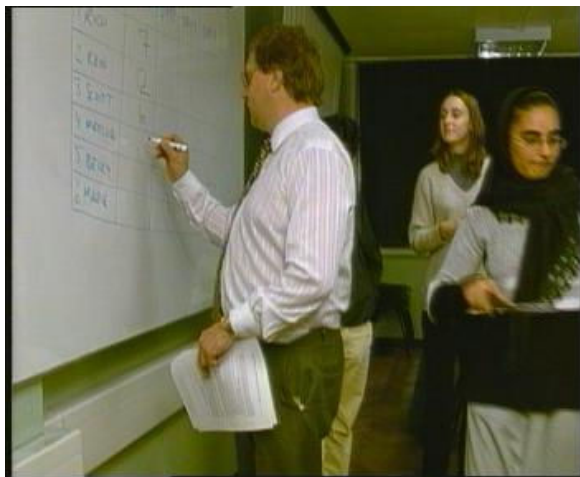
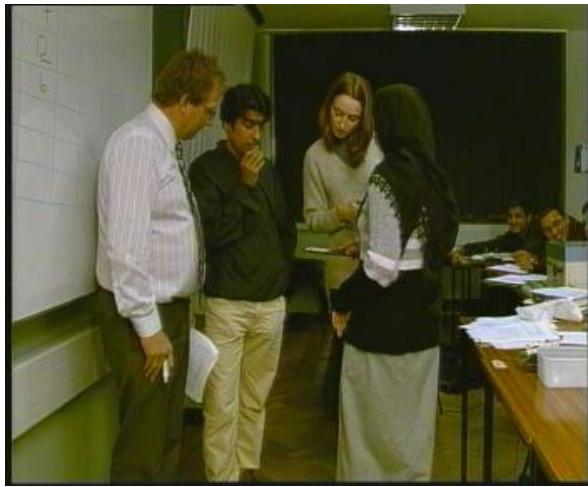
They set out their resources (components, equipment, workers) according to the order in which plugs are assembled, each person carrying out a specific task, e.g. inserting the fuses. The layout type is known as PRODUCT layout.

The first photograph shows the students testing this design. One student is acting as supervisor and is timing and recording the operation, noting bottlenecks, idle time, etc.

The second photograph was taken at the point when the students were reviewing the efficiency of the first design. An alternative design was suggested (a JOBBING process in which each person assembles the entire plug). The students later went on the test this and compare the efficiency of this against the data collected from the first design.

A further test was run using the original design but with the LINE more 'balanced'. This group attempted to develop an algorithm to deal with bottle necks and idle time which triggered a discussion in the plenary about mathematical concepts such as queuing theory, line balancing and process flow charting techniques.

Appendix 1b Simulation:



Deming's Red Bead Experiment

1. Each student (worker) 'makes' the beads and scoops out a sample of 50 for inspection.

2. Quality Controllers check each sample for defective (red) beads over a (simulated) period of 5 days.

3. The Quality Manager records the defective beads in each worker's sample and awards bonuses or punishments according to relative performance.

4. Students then take the data from the simulation and analyse it. They are using a spreadsheet to perform a Statistical Process Control technique (P Chart). The findings are later discussed in the plenary.

Appendix 2: Subject Focus Groups and Project Review Sessions



The student in the first photograph is explaining his group's understanding of the concept of Just-in Time management and the issues it raises within the context of the company the group is studying.

He points out that the power relationship between customer and supplier is a defining factor in the success of this approach and identifies a number of limitations with it in practice. He contrasts this to the idealised view that is often presented in text books.

Other students join in, asking questions and comparing their own research findings to those presented by the group leader.



In this photograph the student is explaining the technique for management of inventory known as Economic Order Quantity (EOQ).

He presents the strengths and weaknesses of this techniques and suggests an alternative technique, Pareto Analysis, could be used instead of or as well as the EOQ formula.

He talks through an example of how this could apply to one of the companies the focus group is researching.

After the plenary session, students worked in their project groups, rescheduling, and updating their project plans.

Appendix 3

Extract from Marking Criteria and Performance Descriptors for PT2003

General Guidance for Students

Subject Specific Outcomes		E grades Answers to examination questions:	D grades Answers to examination questions:	C grades Answers to examination questions:	B grades Answers to examination questions:	A grades Answers to examination questions:
Personal Transferable Skills & Generic Academic Outcomes:						

<p>1. Explain the role, task and importance of the operations management function.</p> <p>Scope: Process choice and process design (facility layout and flow), job design and work organisation, inventory and materials management, internal logistics and capacity management (JIT), quality control and total quality management, forecasting, project planning (critical path analysis).</p>	<p>PTS 1a Produce written work accurately and effectively with the correct use of grammar, punctuation and spelling</p> <p>GAO A Select and use relevant references and quotations to support the points you are making.</p> <p>GAO C Make judgements about the value of evidence, concepts and ideas.</p>	<p>Answers significantly below a level of understanding consistent with core lecture material.</p> <p>No evidence of textbook study beyond lecture notes.</p> <p>Major misunderstandings in theory.</p> <p>Very poor connection between the question asked and answer given.</p> <p>Very poor use of grammar, punctuation and spelling.</p> <p>The logical flow of arguments is generally very unclear.</p> <p>Major deficiencies in the clarity, accuracy and concision of argument.</p>	<p>Answers based around lecture notes.</p> <p>Very little evidence of textbook study beyond core lecture notes.</p> <p>Theory presented as simple fact. No discussion of difficulties or complexities of subject knowledge.</p> <p>Some relevant theory presented in answer to questions but low correlation between the question asked and answer given.</p> <p>No convincing discussion of key issues in student's own words.</p> <p>Poor use of grammar, punctuation and spelling.</p> <p>The logical flow of arguments is unclear in places in a significant way.</p> <p>Some major deficiencies in the clarity, accuracy and concision of argument.</p>	<p>Answers based largely around lecture notes.</p> <p>Some evidence of significant textbook study beyond core lecture notes.</p> <p>Management theory is presented as though perfectly valid and reliable with little discussion of the difficulties and complexity of the subject knowledge.</p> <p>Poor selection of appropriate theory to answer the question asked. Irrelevant and superfluous argument mixed with relevant discussion.</p> <p>Questions not directly answered as asked. Answers present sound theory but in too general a way for the examiner to be sure that a thorough understanding of the issues raised in the question has been demonstrated.</p> <p>Examination answers expressed in terms of lists, little discussion of key issues in student's own words.</p> <p>For essay elements, some major deficiencies in the correct use of grammar, punctuation and spelling (reasonable allowance made for exam conditions and limited time available for proof-reading).</p> <p>The logical flow of arguments is unclear in places.</p> <p>Some deficiencies in the clarity, accuracy and concision of argument.</p>	<p>Demonstrate knowledge of operations management theory by appropriately selecting and accurately citing a number of authors, approaches and perspectives. (Evidence of reading within and around the subject area.)</p> <p>Good critical appraisal of theory by explicitly and clearly discussing strengths and weaknesses of competing theoretical positions, comparing and contrasting different approaches. Identification of areas of debate and problematic issues.</p> <p>Select and bring a significant amount of relevant theory to bear on the particular question asked.</p> <p>Discussion relates well to the specific question asked.</p> <p>For essay elements, mostly correct use of grammar, punctuation and spelling (reasonable allowance made for exam conditions and limited time available for proof-reading.)</p> <p>Good logical flow to arguments.</p> <p>Clear, accurate and concise argument.</p>	<p>Demonstrate extensive knowledge of operations management theory by appropriately selecting and accurately citing a number of authors, approaches and perspectives. (Evidence of wide reading within and around the subject area.)</p> <p>Very good critical appraisal of theory by explicitly and clearly discussing strengths and weaknesses of competing theoretical positions, comparing and contrasting different approaches. Identification of areas of debate and problematic issues.</p> <p>Select and bring the most relevant theory to bear on the particular question asked.</p> <p>Discussion relates strongly to the specific question asked.</p> <p>For essay elements, the correct use of grammar, punctuation and spelling (reasonable allowance made for exam conditions and limited time available for proof-reading.)</p> <p>Very good logical flow to arguments.</p> <p>Very clear, accurate and concise argument.</p>
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		E grades	D grades	C grades	B grades	A grades
<p>3. Use and interpret results of appropriate quantitative and qualitative tools and techniques in the areas of operations design, planning & control and improvement.</p> <p>Scope: as in 1. above and particularly including quantitative techniques in the areas of quality control (SPC), inventory management (EOQ and ABC analysis), critical path analysis and time series forecasting (exponential smoothing).</p> <p>To demonstrate where a quantitative approach to management problem solving is appropriate, important and useful.</p> <p>To demonstrate an understanding and application of fundamental concepts in randomness and variability for the interpretation and evaluation of management data (SPC and safety stock calculations).</p>	<p>PTS 1a Produce written work accurately and effectively with the correct use of grammar, punctuation and spelling</p> <p>PTS 7 Process numerical information related to practical problems and interpret the outcomes.</p> <p>PTS 8a Apply appropriate problem-solving techniques.</p> <p>GAO C Make judgements about the value of evidence, concepts and ideas.</p>	<p>Typically a high number of minor errors or a significant number of major errors relative to the criteria shown for an A grade.</p> <p>Many mistake(s) have been made and not identified, a large number of misunderstandings shown in method and theory.</p> <p>In overall terms less than 40% competence demonstrated.</p>	<p>Typically a significant number of minor errors or two major errors relative to the criteria shown for an A grade.</p> <p>Mistake(s) have been made and not identified, a significant number of misunderstandings shown in method and theory.</p> <p>In overall terms 40% – 49% competence demonstrated.</p>	<p>Typically three or four minor errors or one major error relative to the criteria shown for an A grade.</p> <p>Mistake(s) have been made and not identified, a small number of misunderstandings shown in the method and theory.</p> <p>In overall terms 50% – 59% competence demonstrated.</p>	<p>Typically one or two minor errors relative to the criteria shown for an A grade.</p> <p>Results interpreted logically, e.g. if mathematical mistake(s) have been made but identified (although not corrected within the examination time), and a sound understanding of the method and theory is adequately demonstrated.</p> <p>In overall terms 60% – 69% competence demonstrated.</p>	<p>Select and identify the appropriate data to be processed.</p> <p>Select and identify the appropriate technique to be used.</p> <p>Accurately and correctly process all numerical steps with all workings neatly shown.</p> <p>Report solution(s) to an appropriate level of rounding with units correctly stated.</p> <p>Graphical solutions (where applicable) clearly and neatly presented with appropriate titles, axes, scales and units.</p> <p>Quantitative results accurately and correctly interpreted with appropriate management conclusions clearly stated.</p> <p>Results discussed in the context of underpinning theory where required.</p> <p>Assumptions within which the results are valid correctly articulated with the implications for the breakdown of assumptions given where appropriate.</p>
Overall Grade		E grades	D grades	C grades	B grades	A grades
		<p>21 – 29 = E3 FAIL</p> <p>30 – 39 = E4 MARGINAL FAIL</p>	<p>40 – 42 = D5</p> <p>43 – 46 = D6 SATISFACTORY</p> <p>47 – 49 = D7</p>	<p>50 – 52 = C8</p> <p>53 – 56 = C9 AVERAGE – GOOD</p> <p>57 – 59 = C10</p>	<p>60 – 62 = B11</p> <p>63 – 66 = B12 VERY GOOD</p> <p>67 – 69 = B13</p>	<p>70 – 79 = A14</p> <p>80 – 89 = A15 OUTSTANDING</p> <p>90 – 100 = A16</p>