Overcoming Poor Failure Rates in Mathematics for Engineering Students: A Support Perspective

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Four years ago very high failure rates in Mathematics resulted in poor progression rates on engineering courses at Harper Adams University College. A number of measures were used to remedy this situation. The module content was re-written with a gentler paced introduction, spreadsheets and Mathcad were introduced and a final examination was replaced by two phase tests. Extra support for Mathematics was introduced in several forms. Optional weekly classes provided reinforcement and extra practice of the week's topic, run separately for BSc and HND students. In addition one-to-one support was offered to all students whether BEng, BSc or HND. Support was provided by a college-wide learning support tutor for mathematics and an engineering lecturer. An expensive solution in terms of resources, particularly staff time, but which has proved well worthwhile because of the higher student examination results, confidence in mathematics, and much improved retention rates.

1. INTRODUCTION

'There is clear agreement that mathematical skills are essential. … There is also the need to resolve how changes could be made to the teaching of the engineering sciences, in particular to allow students with different mathematical skills at entry to flourish.' (1)

The 2002/3 first year Engineering students at Harper Adams have enjoyed success and progress in Mathematics, more than their recent predecessors. This is due to support and other measures, which were taken to alleviate poor results and failure cycles, and in response to the challenge of the lack of previously expected knowledge and skills. This paper documents these measures, implemented over the past two years, focussing on learning support, and details the improved maths results achieved. Emotional and motivational effects of student success are also considered important and contributory, alongside more quantifiable outcomes of improved examination marks and retention rates.

Much has been done to enable students with different mathematical skills at entry to flourish which is clearly demonstrated by students results. The approaches taken and student support could be applied to other engineering subjects, other subject areas, and institutions.

2. BACKGROUND

'It's cool to be poor at Mathematics and we've got to change that' (2)

The deficit of Mathematics skills is a national problem of such magnitude that it has been, and still is, the subject of numerous articles and inquiries. The current **Government Post-**

14 Maths Inquiry [3] was established in response to **Set for Success** [4] the Review of the Supply of Scientists and Engineers and **Investing in Innovation: A Strategy for Science, Engineering and Technology.** [5] The Engineering Council have published **Measuring the Mathematics Problem**. [6]

The problem of declining mathematical knowledge and skills of students entering higher education is also widely recognised. Leslie Mustoe of Science and Engineering Foundation Studies, Loughborough University has made the following observations.

'For many years concern has been expressed about the decline in mathematical skills possessed by entrants to engineering and science degree programmes. Students of today perform less well on diagnostic entry tests than those with apparently similar qualifications from the cohort ten years earlier. On its own this decline in key mathematics skills even amongst students who obtained reasonable A level grades would be a significant concern. However, the problem has been deepened by other trends in higher education during the 1980's and 1990's which resulted in a widening of the educational background of entrants to these programmes; the implication of this needs to be appropriately addressed. The growth in the numbers entering higher education has resulted in some students who are less well qualified starting courses to which, previously, they would not have been admitted.

Whilst some subjects such as Psychology and Business Studies, have been able to maintain or even increase their entry qualifications, Engineering and Science have become increasingly less popular and, consequently, have struggled to find sufficient numbers of recruits with the desired level of entry qualification. Any initiatives, which increase motivation among students and give them alternative environments in which to improve their mathematics skills are to be welcomed.' [7]

Neil Challis and Harry Gretton of Sheffield Hallam University describe the lack of pre-requisite knowledge of students.

'There is a widely recognised problem with what can be assumed as pre-requisite knowledge and skills for engineering students newly arriving at university. The problem arises from a complicated set of circumstances including: changes in pre-university mathematics, the diversity of backgrounds of students entering university, … We hope for a certain level of numeracy, including sensible use of the calculator, a certain fluency in algebraic techniques, and some previous acquaintance with the ideas of the calculus. Many students in the group do not have A level Mathematics, so we are frequently disappointed. It is a major task of the module to get students to revisit and enhance previously encountered topics as well as moving onto new topics.' [8]

Harper Adams' students are similar to those described by Sheffield Hallam, many have studied National Diploma courses rather than traditional A level mathematics and physics, and lack desirable pre-requisite knowledge. They also lack confidence in their mathematical abilities. Difficulties have arisen across the college's range of courses, with mathematical content and on statistics modules, which experienced high failure rates. Students' lack of mathematical ability (not having Grade C GCSE Mathematics) was suspected and investigated as a contributory factor in student withdrawals. Harper Adams lecturer Charles Cowap found that ***'there was a strong (95 to 98%) probability that the lack of GCSE Mathematics Grades 'A' to 'C', was a significant factor in the withdrawal of students from the 1995 HND and Degree entry to the college.'*** [9]

Confidence and belief in one's own ability is particularly important in Mathematics as described by Paul Ernest, of the University of Exeter.

'There is growing evidence of the importance of students' attitudes and beliefs about mathematics for their achievement and successful applications of the subject. [10] ***Research studies have shown that students in Higher Education who are not maths majors often have negative images, beliefs and attitudes towards mathematics.*** [11] ***There is great variation across all students, especially engineering students, who can be mathematically very strong through to some who are quite weak. It is often but not invariably the case that mathematical achievement is correlated with positive attitudes to the subject. Typically, it is confidence in one's own mathematical ability that is correlated with achievement, rather than liking or pleasure in the subject.***

Where such correlations do occur it is observed that the achievement-attitude link forms self reinforcing cycles. [12] See Figure 1.

Low achievement or repeated failure in maths often leads to negative attitudes and lowered confidence, resulting in reduced effort or even maths avoidance, leading to further failure. This is a vicious cycle.

Positive achievement and success in maths often lead to enhanced attitudes and raised confidence, resulting in increased effort and persistence and further success.'

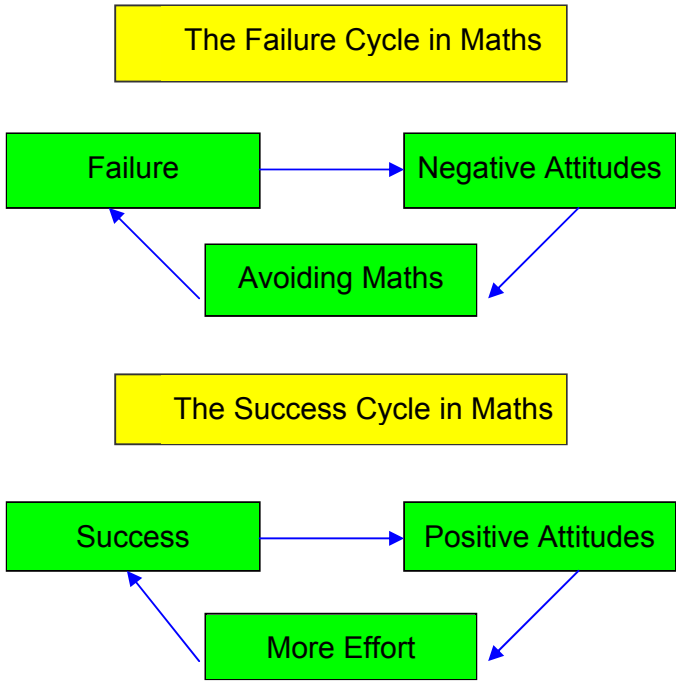

Figure 1. Failure and Success cycles in Maths [13]

We now have success cycles in first year Mathematics modules, which will fuel further positive attitudes, effort and success across engineering subjects that use mathematics.

3. IMPROVED RESULTS

First year engineering mathematics successful results - 2002/2003

HND Marks 2002/3						
	Semester 1	**Test 1 50%**	**Test 2 50%**	**Semester 2**	**Test 1 50%**	**Test 2 50%**
Students	23	23	22	17	16	16
Mean %	64.1	66.3	64.2	59.1	62.5	62.3
St. Dev.	22.6	19.8	25.5	20.3	20.8	13.7

BSc Marks 2002/3						
	Semester 1	**Test 1 50%**	**Test 2 50%**	**Semester 2**	**Test 1 50%**	**Test 2 50%**
Students	17	17	16	20	19	19
Mean %	73.5	83.4	67.1	66.9	73.3	66.8
St. Dev.	20.2	15.2	24.7	19.0	15.5	16.7

BEng/MEng Marks 2002/3						
	Semester 1	**Test 1 30%**	**Test 2 70%**	**Semester 2**	**Proj 30%**	**Test 70%**
Students	16	16	16	17	17	17
Mean %	79.6	85.8	76.9	70.5	61.5	74.2
St. Dev.	18.5	14.0	21.4	13.1	6.3	16.9

Poor results for comparison from 1999/2000

HND Marks 1999/2000						
	Semester 1	**Test 1 30%**	**Test 2 70%**	**Semester 2**	**Test 1 40%**	**Test 2 60%**
Students	12	12	12	12	12	12
Mean %	49.1	55.8	50.3	31.1	34.3	29.1
St. Dev.	25.5	21.3	26.4	21.2	21.9	22.3

Degree Marks 1999/2000						
	Semester 1	**Test 1 30%**	**Test 2 70%**	**Semester 2**	**Test 1 40%**	**Test 2 60%**
Students	18	18	18	24	24	24
Mean %	53.7	58.8	51.4	45.7	47.6	44.3
St. Dev.	20.9	23.0	22.3	16.7	17.5	20.8

Percentage improvement in mean marks from 1999/2000 to 2002/3

HND Semester 1	30.5%	HND Semester 2	89.9%
BSc Semester 1	36.9%	BSc Semester 2	46.3%
BEng Semester 1	48.2%	BEng Semester 2	54.3%

The 1999/2000 first year HND cohort was decimated with only 5 out of 12 students passing the Mathematics first time, thus 58% withdrew, caused primarily by their failure at maths. The degree cohort from the same year experienced a 33% failure rate, 8 out of 24 degree students failing the mathematics. Some withdrawals have occurred in 2002/3 but fortunately these have been minimal.

External examiners have commented each semester on the improvement in the mathematics results over the past two years.

The system now works! In contrast this year many students have now achieved A grades and Distinctions, despite having arrived without pre-requisite mathematics skills and qualifications**.** Many had not studied either A level Mathematics or Physics, and had only Intermediate GCSE Mathematics. Some had only GCSE Grade 'D' and even 'E', plus Numeracy/Mathematics from their National Diploma courses.

Actual 2002/3 degree student details are as follows:

GCSE Mathematics	**ND Applying Numeracy**	**Maths Test Results**			
Grade D	**None listed**	**83%**	**81%**	**73%**	**77%**
Grade D	**Merit**	**76%**	**54%**	**83%**	**71%**
Grade E	**Pass (Engineering Maths)**	**85%**	**56%**	**73%**	**62%**

The results of both of the past two years have also shown some less naturally able students performing better than more naturally able students due to taking up the support and their sheer hard work – a 'tortoise and hare' phenomenon! Current second year HND students who lead their cohort required support to pass Mathematics in their first year, this proves that these students are worth the investment of Mathematics support.

4. THE SUCCESSFUL APPROACH

The changes to the Mathematics modules, teaching and support over the past two years are listed below and described in detail in order of occurrence.

Modules redesigned
Student support and encouragement
Early diagnostic testing with counselling of weaker students
Excellent teaching and course handouts
Split examinations
Close communication between support and lecturing staff

4.1 *Diagnostic Testing*

A 1 hour diagnostic Mathematics test during student induction identified weak students who were counselled to seek support and encouraged to do extra work. A 10-minute college-wide numeracy screening test also gave comparable results.

4.2 *Lectures*

Students were lectured separately in the three award groups: HND, BSc and BEng/MEng, with graded module content. Principal and Senior engineering lecturers delivered the

modules and one hour a week for support was timetabled for HND students with a third engineering lecturer.

The Semester 1 content was redesigned to include previously assumed material, for example basic algebra and scientific notation, but progressed rapidly to harder Mathematics topics, for example complex numbers and matrices, as required by the Engineering Council. Students now learn more, due to starting at a lower level, but still achieve the same end objectives. Teaching is no longer at a flat rate but follows an exponential curve, increasing the pace of learning as the year progresses.

Distinctive characteristics of the lectures were:

- **Pre-requisite knowledge not assumed**
- **Excellent handouts** which contained
  - **theory (**lectures not taken up with dictation),
  - **worked examples,**
  - **student exercises and answers**
- **Teaching by worked examples**
- **Students worked through exercises** in the lecture, thus immediately putting into practise theory and methods learnt. The exercises were progressively difficult, which enabled all students to achieve some success whilst the more able had sufficient challenging work to do.
- **Answers provided -** students checked their own work and could work outside lectures, especially for revision.
- **Different exam papers** for each award level.

4.3 ***Learning Support***

A new post was created for a college wide Learning Support Tutor who gave regular small group, and individual appointments on demand, to help the engineering students with mathematics. Weekly Group 'Extra Maths' times were published for BSc and HND students separately. Attendance was greatest during the first 7 weeks when the students struggled to settle in and grasp the basics of algebra, and for exam revision.

The learning support tutor's Extra Maths followed this format:

- **Theory re-explained from basics**, not assuming that the students had understood or remembered the lecture content, or had necessary pre-requisite knowledge.
  Method broken down into further specific steps.
- **Pace to suit** students – weakest students benefited most from individual support
- **Illustrations** used wherever possible (a picture paints a thousand words) and examples to suit range of learning styles. For example, a pond that doubles in size (diameter) daily is an example of an exponential function.
  As is the growth in the population of wild rabbits!
- **Maximum Student participation**
  - Students were **asked questions**
  - **Worked through exercises**
- **Students praised** and encouraged where possible
- **Light-hearted style**

Examples of degree student feedback comments (May 2003):
'Maths Support was very useful, without I don't believe I wouldn't have passed this module. But now I'm getting "A" grades in my exams'

'Maths support was very helpful. Without it I may not have passed my exams.'

'Very helpful and understanding teacher'

Students from each award level have taken up the support. For the BEng/MEng group the Maths was more difficult so, whilst being more able students, some had not taken either Maths or Physics A level, so lacked necessary prior knowledge and needed help.

Other characteristics of the learning support was that it was presented in a friendly, informal and approachable manner. Basic mathematics, in particular fractions, often cropped up in work with students at all levels, often addressing weaknesses that had persisted from primary schooling days. The individual and small group times were in themselves a motivational factor for students who knew that an interest was taken in their work. The existence of the support facility was also a reassuring factor because students knew that help was available if they found topics difficult.

Comprehensive feedback for the engineering maths learning support was gathered via lecturers at the end of the year, giving ratings of between 4 and 5 out of 5 for all aspects of the support feedback. Thus showing high levels of student satisfaction with the support received.

4.4 *Student Effort*

Credit is also due to the persistent hard work and raised self-confidence of many students. Without the students themselves making the extra effort the results obtained could not have been achieved.

5. CONCLUSION

The current success of Harper Adams' first year Mathematics modules in Engineering is a welcome improvement on past results. Many students have succeeded, including those with low prior qualifications. Contributory factors of the improvements are course redesign, student support, raised student self-confidence through success and encouragement, student effort and diagnostic testing. The personnel costs associated with student support have been more than repaid with greatly improved student progression and retention rates. Other departments and institutions teaching mathematics would benefit from adopting this approach.

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