

Supporting Mathematics Education in UK Engineering Departments

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Abstract— *The past decade has seen a serious decline in students' basic mathematical skills and level of preparation on entry into higher education in the UK [1], causing many students to embark on engineering degree programmes without the necessary maths skills required for the course. It is considered that the 'maths problem' has arisen from a number of factors including:*

- *Widening of access to higher education – resulting in the acceptance of students with much more diverse backgrounds and experiences of mathematics than previously.*
- *Inadequate mathematics preparation in school (pre-18 education) - due to a variety of causes including curriculum shortcomings, emphasis on assessment and league tables, shortage of mathematically qualified teachers, and social influences.*

Unfortunately, the 'maths problem' is unlikely to be resolved at school level, at least in the medium-term, and so the responsibility lies with universities to combat this issue. In June 2000, the UK's Engineering Council [EC(UK)] recommended to all universities that students embarking on mathematics-based degree courses should have a diagnostic test on entry, and that prompt and effective support should be available to students whose mathematical background is found wanting by the tests. In April 2001, the engineering and mathematics higher education communities were surveyed to investigate how departments are responding to these issues and the EC(UK)'s recommendations. The survey received an excellent response and as a result, the LTSN MathsTEAM project has been developed to provide national resources to allow the transfer and embedding of both diagnostic testing and follow-up support into the UK engineering and mathematics higher education communities. Further funding has now been obtained to create a web-based UK Mathematics Learning Support Centre – mathcentre. The findings from the survey, the LTSN MathsTEAM project and mathcentre are discussed in this paper.

Index Terms — *diagnostic testing, mathematics support, mathematics teaching, UK resources*

INTRODUCTION

Engineering as a profession requires a clear understanding of mathematics, science and technology[2]. In the field, mathematical and scientific theories and principles are applied to real life situations and used to develop economical solutions to technical problems. Algebra and analysis, probability and discrete mathematics are part of a large common core. Several more specialised topics are needed for particular branches of engineering [2]. It is vital therefore, that the engineering graduate acquires not only an empirical but also abstract understanding of mathematics [3].

Over the last ten years, Engineering Institutions have been faced with the growing challenge of undergraduates being accepted on degree courses with relatively low mathematical qualifications [4]. For instance the Engineering Council in 1995 [4] published the results of a detailed study into the nature and extent of the difficulties which undergraduate engineers face with mathematics. More than half the lecturers surveyed described the mathematical background of the students as undermining the quality of their engineering degrees [5].

A number of institutions have made recommendations. In September 1999, the Institute of Mathematics and its Application (IMA) made the suggestion that, in both the Incorporated Engineers (IEng) and the Chartered Engineers (CEng) programmes, mathematics topics should be taught within an engineering context. In June 2000, the UK's Engineering Council recommended to all universities that those students embarking on mathematics-based degree courses should have a diagnostic test on entry and that prompt and effective support should be available to students whose mathematical background is found wanting by the tests.

There is growing evidence that universities throughout the UK are responding to the lack of mathematical skills amongst engineering students. This information has now been collated in three resource guides published by the LTSN MathsTEAM, based on its survey of current innovations in the assessment of students, the different types of student support being developed by departments and new initiatives in the delivery of mathematics to engineering students.

Recent government funding is now providing for the creation of a national mechanism for mathematics support, to enable universities to share resources rather than duplicate effort. This is in the form of the web-based UK Mathematics Learning Support Centre – **mathcentre**.

TESTING STUDENTS ON ENTRY TO HIGHER EDUCATION

Many Engineering, Physics and Mathematics departments throughout the UK are carrying out diagnostic tests to assess the current mathematical ability of students on entry. Table 1 shows the findings of a departmental survey conducted in April 2001 by LTSN Engineering, LTSN Maths, Stats & OR Network, the UK Centre for Materials Education and LTSN Physical Sciences. Academics were asked to confirm whether their department conducted diagnostic tests or not. The results indicate a large number of institutions were carrying out diagnostic testing. Exploring these facts further, descriptions based on the types of testing were submitted to the LTSN MathsTEAM Project at the beginning of 2002.

In most cases, the diagnostic test was carried out during the induction week or the first few weeks of the academic year. The number of students sitting the test varied; the figures submitted went as high as eight hundred in a single institution. Some universities gave students a diagnostic test designed for specific engineering courses, e.g. mechanics.

“The methodology for the testing ranges from intelligent diagnostic systems to computer generated multiple-choice questions through to paper-based tests (with paper-based test being used in 68% of departments). The responses on a paper-based test may be entered on Optical Mark Reader (OMR) paper and marked by the computer or the whole process undertaken manually.”

The tests are not standardised, but in several departments, the same diagnostic test has been used over a number of years. Each covers a variety of mathematical topics and departments use the results to assist the students in different ways.

For one institution, the department requires all the new engineering students to take a computer-based test called Diagnostics in the entrance week. In this case:

“The students must achieve 60% or more by week nine. If they fall below the 60% level, they have various times when they can re-take the test up to week nine. There are no specific classes arranged for those who do not achieve the result the first time.”

For another department, the process is quite different:

“About 100 students enter the engineering degree course each year, all of whom have A-level maths or its equivalent. During the first week, they sit a diagnostic test and, based on this test and their entry qualifications, about twenty students are selected to attend extra classes. Of these twenty students, the weakest 10-12 are selected to attend a further hour per week in a tutorial class, given by an A-level teacher from the local 6th Form College.”

Regardless of the lack of standardisation, the test results for many departments help them devise approaches to adjust the mathematics teaching and curriculum to the needs of the group and also to inform subject specialists' expectations of their students mathematical abilities. Primarily the test is being used to help departments to devise strategies to support engineering students with different attainment [1].

For example, at one institution students starting a maths, engineering or science degree, sit a forty minute test covering six sections (arithmetic, algebra, trig, logs/exponentials, differentiation, integration):

“Those who did poorly on a section or who did sufficiently poorly all round are asked to attend a class on that section. For some topics, web-based material is available and students are asked to attempt further questions before attending a ‘remedial session’.”

Such support strategies indicate changes to the teaching curriculum of departments to accommodate the decline in skills. It should be noted at this point that some universities choose not to give the students a diagnostic test, believing this to be too frightening an experience for a student in their first week at university. However many of these institutions do see the need to support their students and have mathematics support strategies in place.

MATHS SUPPORT FOR ENGINEERING STUDENTS

In the past traditional undergraduate engineering programmes consisted of lectures on different mathematical topics that were supported by both tutorials classes and problems. These were carefully marked and discussed with the students [6].

Over the last ten years, there is clear evidence that this pattern has changed [6]. There is a shift to a more diverse selection of teaching and support strategies. The lecture may have been retained, but the tutorials have become more structured or have been replaced by other methods of support for student learning, both independent and staff directed.

The LTSN April Survey 2001 covered the topic of student support (see Table 2). Academics were asked to indicate whether they provided support facilities for mathematics or not.

To find out more about the types of activities which were being implemented the LTSN MathsTEAM Project asked academics to submit brief descriptions of the different types of student support available. Forty-one engineering and mathematics departments replied providing details of the many combinations of activities being developed.

These included:

- institutional and departmental student support
- maths support centres and drop-in centres
- student support via other students
- summer schools and bridging courses
- test-based, computer-based, paper-based and web-based support.

Usually, support is being provided not only when the student arrives, e.g. through refresher courses, but also long-term strategies have been put in place to assist throughout the academic year. A good example of this type of holistic approach is as follows:

“For a first year Engineering Mathematics module, contact with students takes the form of a two-hour lecture followed by a one-hour tutorial session. Support to students takes on a number of different forms. The tutorials are organised so that some weeks an extended problem is set, in other weeks students work through some short exercises. It is in these sessions that problems are identified. Students can obtain one-to-one tuition by appointment either with their tutor or through a drop in surgery, which operates for one hour each day from the Maths and Statistics Learning Centre.

Students sit four computer-based tests during the year on algebra, calculus, differential equations and linear algebra. Each test is open for two weeks and students can have three attempts at the test. Students therefore get an ongoing indication as to how well they are progressing and they can seek help if necessary.”

The LTSN MathsTEAM survey suggests that in managing the lack of mathematical skills, departments have moved beyond the traditional lecture and tutorial system to a network of supporting initiatives. For instance at one university:

“A stage one module “Basic Mathematical Techniques” is scheduled for the first semester. This module acts as a “Bridging Module” providing a subset of the ‘A’ level syllabus with particular focus on calculus, functions and graphs and aspects of algebra.

A weekly mathematics clinic is also provided throughout the teaching year. This support is offered on a drop-in basis to all university students accessing mathematical modules. The clinic is timetabled to be accessible to all stage one and two specialist mathematics students. Friendly, approachable and experienced members of staff, run the clinic.

The computer package TRANSMATH is available in specialist PC laboratories provided within the School Computing and Technology and in the University Learning Centre.”

Such strategies are becoming a part of the teaching process of engineering students for many universities. Each is fulfilling a growing need, and once implemented they are becoming part of the teaching methodology of the department and the student's tools. They provide the undergraduate with an understanding of their mathematical weaknesses and the opportunity to address them.

Each approach attempts to deal with the fact that engineering modules are assuming knowledge and skills, which some students do not have, particularly in number and algebra. In addition, they are attempting to address the mathematical diversity of the student intake [5]. The problem with supplementary resources and additional tuition are they deal with isolated problems and do not provide a means of constructing a coherent mathematical knowledge base for the student [7].

In reviewing the mathematical skill-based problem, the report *Engineering Mathematics Matters* maintains that when planning courses and student support the limitations of the students' previous education must be taken into account.

The report goes on to provide recommendations and guidelines including a new mathematics syllabus for students on IEng accredited courses [7]. Based on a core curriculum, the syllabus is divided into three levels, the first of which is crucial for the student to understand.

In full, seven recommendations were made based on this new syllabus, one of which was that the core curriculum topics, which are presented as a list of abstract mathematical topics, should be taught within an engineering context.

TEACHING MATHEMATICS WITHIN AN ENGINEERING CONTEXT

“Mathematics for the engineering student should be regarded as a language of expressing physical, chemical and engineering laws” [3:151]. Thinking mathematically in a scientific and engineering context however requires knowledge and skills that will make the knowing efficient and effective [8]. For many engineering students the lack of this coherent knowledge base is affecting their ability to obtain an empirical and abstract understanding of mathematics.

There are ongoing discussions based on the teaching of mathematics to engineering students. There are examples where the “problem context, be it mathematical or ‘real’, seems to interfere with the correct use of even a simple technical skill” [8]. For instance, students had little difficulty when asked to evaluate the following question:

(1)

But when faced with the following the students “technical facility seemed to desert them and there were a large number of incorrect evaluations [8:3]”:

***Find the area enclosed between the curve
 $9y^2 = 4x^3$ and the line $x = 1$.***

In the report *Engineering Mathematics Matters* [7:12], it was recognised that in the teaching of engineering undergraduates “the emphasis has been placed on cramming students who are poorly-prepared mathematically with large amounts of material, which they often fail to assimilate. Satisfactory progression is usually based on testing a subset of this material in an examination in which, frequently, students are able to select from a range of questions”.

In addressing such issues, the report provides many suggestions. However, it is beyond the scope of this project to explore all of them. Therefore, the study has concentrated on the recommendation that “where possible, the mathematics topics should be taught within an engineering context” [7:20].

The LTSN MathsTEAM project has explored this suggestion by asking academics to describe their method of teaching maths if directed towards specific engineering topics, such as fluid mechanics or thermodynamics.

The descriptions covered all years, from foundation year through to final year. In general the teaching methods illustrated that in developing mathematical thinking “engineering students need to be set worthwhile tasks, but tasks that are so structured that they are accessible to the weaker students as well as the more able” [8:4]. Every teaching method focused on the needs of the students. The aim was to create good practice, which would engender mathematical thinking within an engineering context [8]. For instance, the development of a series of computer-based problems involving Mathcad for one academic had two objectives:

“Firstly, relating the mathematics taught to engineers to real practical problems. This is particularly important in the motivation of engineering students. Seeing that real engineering problems can be solved by a combination of classical mathematics and numerical mathematics has led the students being prepared to tackle projects using their mathematics. Secondly, the students get experience of a mathematical package which is extensively used in industry.”

Technology formed the basis of the contextual approach for many of the academics. For example: -

“In our Engineering Analysis module we cover Complex Analysis, Transform Theory and Applications, and Stochastic Processing. We use MATLAB as the main computer aid for the course material. MATLAB is also used to teach non-linear mathematical modelling in a Neurocomputing undergraduate course and at the postgraduate level to teach similar Mathematical concepts. These include DSP Theory, Simulation Techniques, DSP Implementation. Overall, I find that the use of MATLAB aids the complex mathematical ideas to become clearer for the students.”

For some the approach was 'fun', as one academic described the teaching method of a Mathematical Modelling course taught to first year chemical engineering students. This involves thirteen lectures, which are supported by 2x2h problem classes (repeated twice; half the class each time):

“These problem classes are quite interactive with group work, group presentations, individual presentations and use of game show formats. The “Ready Steady Cook” voting system is used for whole group responses and there is a “Who wants to be a modell..aire?” game. We are thinking about a “Weakest Link” variant. Chocolates are used as prizes. Much fun is had, and attendance is very high. Much better than the old way of doing things.”

Overall, the mathematical principles need to be linked to engineering applications to promote relevance and the understanding of mathematics for the students. In one example in teaching control engineering, the academic has moved from Laplace Transforms to z-transforms on the grounds that computer control is discrete as opposed to continuous. This change has enabled the academic to implement simulations using a spreadsheet. He goes on to say: -

“The advantage using spreadsheets is that there is no clever package between the student and the solution. Everything that happens is programmed by the student and is no more than a few simple recurrence relationships. The students understand it, they like it, it’s fairly easy and they can examine the way a control system responds as the parameters are changed.”

Such innovations in learning and teaching methodologies are becoming more important. Generally, there is a growing need for a more holistic approach to teaching maths to engineering students. This would include:

- Finding "the right balance between the practical applications of mathematical equations and in-depth understanding" [3:1].
- Establishing a systematic development of numeracy, literacy and information technology key skills within all engineering departments [9].

- Making sure students are exposed to and are proficient in using technology [5] to aid engineering processes.

One of the most important aspects is that engineering students need to understand that the knowledge of mathematics is essential to their future practical work [3].

CONCLUSIONS AND FUTURE DEVELOPMENTS

The LTSN MathsTEAM has focused on current changes in the provision in mathematical education for engineering students. The descriptions submitted illustrated an upheaval in pedagogical and assessment methods and showed that technologies appropriate to the subject matter are being utilised:

- The survey on diagnostic testing illustrated a growth in the assessment of basic mathematical skills on entry to higher education.
- The review of student support presented a variety of initiatives that are becoming embedded within the curriculum.
- Academics are exploring innovative methods of teaching maths within an engineering context as they face the task of ensuring that mathematical manipulation does not become a scarce ability amongst graduate engineers [8].

Each of these illustrates that universities are individually facing the challenge of supporting mathematics education within engineering departments. Clearly the optimum place to provide mathematics support is within the students' university. The UK government has recently provided funding to create the UK Mathematics Learning Support Centre – **mathcentre**, which will offer all universities the opportunity to establish or enhance their local provision. **mathcentre** will ensure that all stakeholders - students and university professionals - have access to a nationally available resource bank so that high quality support can be offered efficiently, cost-effectively and rapidly. Resources are already available to download from **mathcentre**, which can be found at **www.mathcentre.ac.uk**.

The LTSN MathsTEAM project has focused on harnessing collective intelligence, capturing good practice, sharing lessons learned and making explicit the knowledge of academics throughout the UK. Case studies and other resources are available from **www.ltsn.ac.uk/mathsteam** to support academics supporting student learning and performance.

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FIGURES AND TABLES

TABLE 1

LTSN DIAGNOSTIC TESTING SURVEY, APRIL 2001

<i>Question: In 2001 were new undergraduates in your department given a mathematics diagnostic test?</i>			
	Number of Responses	Yes	No
Engineering departments	59	38	21
Mathematics departments	54	32	22
Physical Science departments	50	31	19
Materials departments	8	2	6
TOTAL	171	103	68

TABLE 2

LTSN STUDENT SUPPORT SURVEY, APRIL 2001

<i>Question: In 2001/2 was remedial support available to students whose mathematical background has been found wanting?</i>			
	Number of Responses	Yes	No
Engineering departments	61	55	6
Mathematics departments	55	49	6
TOTAL	116	104	12