Addressing the Mathematics Problem within Engineering Education: New Approaches being Piloted at a UK University

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Abstract *— The engineering profession requires a clear understanding of mathematics, science and technology. However, work by the UK's Engineering Council in 2000, suggests that the past decade has seen a serious decline in students' basic mathematical skill and level of preparation on entry into higher education in the UK. This decline is reportedly due to the widening of access to higher education and inadequate mathematics preparation in pre-university education. A study by the Institute of Mathematics and its Applications, conducted in 1995, suggests that this decline in mathematical preparation is perceived as threatening to undermine the quality of Engineering Degrees in the UK. As part of the work of the Mathematics Education Centre at Loughborough University, new measures are being implemented to help address the diversity of mathematical skill amongst students studying Electronic and Electrical Engineering. These measures include pre-sessional courses, one-to-one action planning with students identified as at risk of failing or underachieving, and workshops in key mathematical topics. These new measures are designed to complement existing practices at the University, including diagnostic testing and the Mathematics Learning Support Centre. The paper discusses the rationale for the measures being implemented and provides details on how pre-sessional courses for upcoming students with non-traditional mathematical backgrounds are run. The paper also discusses the effect of these measures, the lessons learnt from their implementation and makes suggestions for how these measures could be transferred to other institutions*

Index Terms *— Mathematics for Engineers, Mathematics Problem, Mathematics Support, Pre-sessional Course*

INTRODUCTION

According to SARTOR UK (Standards and Routes to Registration), Engineering is a profession directed towards the skilled application of a distinctive body of knowledge based on mathematics, science and technology [1]. Over the past decade, a problem has arisen in many UK engineering departments, with departments observing a serious decline in students' basic mathematical skill and level of preparation on entry into higher education [2]. This problem is attributed in part to:

- Inadequate mathematics preparation in schools – resulting from "curriculum shortcomings, an emphasis on assessment and league tables, a shortage of mathematically qualified teachers and social influences" [3].
- Widening of access to higher education to include students with more diverse backgrounds and experiences of mathematics [3].
- The pressure on UK universities to admit increasing numbers of students, and consequently having to reduce the A level grade requirement for entry [1].

A study by the Institute of Mathematics and its Applications, conducted in 1995, suggests that the decline in mathematical preparation is perceived as threatening to undermine the quality of Engineering Degrees in the UK [4,5]. In light of the growing 'mathematical problem', the Engineering Council, in 2000, recommended 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" [2]. Many UK universities have taken up the practice of diagnostic testing and follow on support. A study by the Learning and Teaching Support Network (LTSN [6]) 2001 found that diagnostic testing and support strategies are "becoming part of the teaching process of engineering students for many universities" [3]. These strategies are not only dealing with the fact that engineering modules are assuming mathematical knowledge and skill but they are also attempting to address the mathematical diversity of the student intake [5].

Pre-University Qualifications

In the UK there are a variety of qualifications that students can gain before entry into university. The standard route is through GCSEs and A Levels. GCSE's (General Certificate of Secondary Education) are usually taken at the end of compulsory education at sixteen years of age. Typically students take nine subjects. A Levels (General Certificate of Education Advanced Level) are usually taken at the age of eighteen in three or four subjects. An AS Level qualification can be taken at seventeen, this typically constitutes half an A Level. As an alternative to A Levels, students wishing to take more vocational courses can take BTEC courses (Business and Technology Education Council) at Colleges of Further Education. In addition to A Levels, a BTEC III qualification is recognised by universities in the UK for the purpose of entry to degree programmes. [7]

SUPPORT ACTIVITIES: TARGETING STUDENTS WITH NON-TRADITIONAL MATHEMATICS BACKGROUNDS

The heterogeneous level of mathematics ability in a student cohort, resulting from increasingly diverse mathematics backgrounds, makes it difficult to pitch lectures at a level at which all students can follow. Without intervention students without the assumed mathematics knowledge and skill may be in danger of failing or underachieving. Within the Department of Electronic and Electrical Engineering at Loughborough University, students without A Level mathematics are accepted onto courses offered by this department if they are able to demonstrate, on an individual basis, ability in other mathematically dependent subjects. This group of students (those with non-traditional mathematics backgrounds) is further enlarged by students with alternative qualifications to A Levels and also by mature students. With their diverse backgrounds it is possible that these students may have gaps in their knowledge or they may not have used their mathematics skills for a considerable period of time, increasing the risk that they may struggle in traditional mathematics lectures.

The Mathematics Education Centre (MEC) at Loughborough University has recently expanded the support that it offers to engineering students to include support targeted specifically at students with non-traditional mathematics backgrounds. The additional support comprises three activities: a pre-sessional course (summer school) covering key algebraic topics and key (transferable) skills relevant to engineering; action plans and fortnightly meetings with students falling below a threshold mark on a mathematics diagnostic test; and lunchtime workshops on key mathematics topics. The following provides an overview and rationale for each of these activities.

Pre-sessional Course

In 2003, the Mathematics Education Centre (MEC) [8] and the Engineering Education Centre [9] jointly piloted a pre-sessional course for eleven, upcoming, first year, Electronic and Electrical Engineering students with non-traditional mathematics backgrounds. The aims of the course were to:

- Raise awareness of the mathematical and engineering support facilities available at Loughborough University.
- Reinforce the need for mathematical competency with regards to engineering degree courses.
- Begin the process of strengthening mathematical competency in essential topics.
- Aid the development of key skills relevant to engineering.
- Increase student confidence.

The residential pre-sessional course ran for a total of four days and combined mathematics workshops with key skill activities, team based problem solving and social activities. A mix of activities was provided to make the course attractive to prospective students and to enable students to develop key skills essential on an engineering degree course at Loughborough University. The mathematics sessions concentrated on basic algebra and covered topics such as the transposition of formulae and factorising. In the workshops each topic was introduced to students with worked examples before students attempted practice questions on their own; the MEC's Algebra Refresher booklet [10] formed the source of practice questions used in these workshops. Additional members of staff were available in these sessions to help students on an individual basis.

Key skills sessions covered topics such as oral presentations, time management, and team working. In each session students were encouraged to actively participate, practicing their skill in a supportive environment. Additional sessions were also incorporated into the programme; these included a question and answer session with past students from the Department of Electronic and Electrical Engineering, a tour of the library and its facilities and a tour of Loughborough Town Centre. Organised entertainment was provided each evening for the students. The rationale for providing structured entertainment was both to help students to bond with each other and to forestall any behavioural problems with 18-year-old students being away from home for the first time. Activities included ten-pin bowling and meals out at themed restaurants.

A four-day residential course covering mathematics and engineering key skills can do little to address significant gaps in mathematical knowledge. However, the rationale for the course was to expose students, those at greatest risk of failing or underachieving on their degree course, to the support staff and facilities that will be available to them whilst at University. By giving students a positive experience of the types of support offered by the MEC, it was anticipated that students would be more likely to seek out or accept support if they later struggled with the mathematical demands of their course. Additionally, by bringing together students with non-traditional mathematics backgrounds, students could meet and befriend others in a similar situation. It was felt that this could give students both a morale boost and a strategic benefit on a course dominated by students with A Level mathematics.

A dedicated member of staff was employed part-time, as a progression officer, by the MEC to organise and run the pre-sessional course. A further four members of staff taught mathematics and key skills workshops on the course. A detailed account of the course, its costs and staff hours can be found in [11].

Action Plans

Organised by the MEC, all first year engineering students, including those from the Department of Electronic and Electrical Engineering, take a mathematics diagnostic test in the first week of term. These tests are used to identify students who have significant gaps in their knowledge. As part of the MEC's strategy to help students at risk of failing or underachieving, all Electrical Engineering students whose diagnostic test marks fell below a threshold mark were contacted by the progression officer, including those students invited to attend the pre-sessional course. Responding students worked with this member of staff to address the areas of weakness identified by the diagnostic test. The MEC's Mathematics Learning Support Centre (MLSC [12]) houses a wide variety of resources. Students were encouraged to access these resources and to work through these in their own time. The progression officer met individually with each student on a fortnightly basis, enabling the student to ask questions. This allows student progress to be monitored and for their study to be directed. Over the course of the year, as a student's ability improves, the focus of the action plan meetings changed to mirror the content of the mathematics module. The performance of all Electrical Engineering students was monitored throughout the year and offers of additional support were made to those identified as underachieving.

By responding to poor diagnostic test performance with the offer of one-to-one support from a dedicated member of staff, it was intended that:

- Students would understand the importance, to their engineering degree, of having mathematical competence.
- Students would engage in effective study that will increase their competence and confidence.
- Students would be encouraged to fill their knowledge gaps by studying in their own time.
- Students would be introduced to the other support resources and facilities available through the MEC, including the MLSC's staffed drop-in centre.

It is recognised that a certain degree of commitment and motivation is required from students in order for them to benefit from this form of support. Support was offered to forty-two students. Whilst fifteen students signed up throughout the year to receive action plan support, only six continued to meet beyond the first two months. Many of these remaining students continued on action plans for the entire year. Some of the students, who only attended a few action plan meetings, chose instead to attend the workshops outlined below.

Term-Time Workshops

The third form of support offered to students, in addition to the MEC's existing support activities, was optional workshops. A series of workshops were run over the year, usually taking place once a week during lunchtimes, although two-day workshops during lull periods at the end of the semester also proved popular. Each series of workshops typically comprised eight one-hour sessions, covering topics such as algebra and calculus. Workshops were voluntary with students choosing to attend as few or as many as they liked. At the beginning of each workshop students were asked to sign a register in order to keep a record of attendance.

In a typical workshop the topic is explained on the board with examples before students practice the set questions that accompany the handout. Workshops were typically small, with rarely more than ten students attending a session. This small group environment and the relaxed nature of the workshop meant that the pace of the workshop could be matched to student ability. Students felt able to stop the class and ask questions; something that they feel unable to do in a lecture theatre of over one hundred students.

Action plan support requires a degree of commitment and motivation from students to work in their own time, however, one-hour workshops, requiring no booking or preparatory work, require little commitment from students. These workshops have been provided to target students who may struggle with a particular topic in lectures but who do not need or who are

unwilling to commit to a greater level of self-study. Whilst these workshops were aimed at Electronic and Electrical Engineering students, they were advertised across campus via email. Student attending the workshops came from departments as diverse as Economics, European Students and Mathematical Sciences, in addition to Electrical Engineering.

EFFECTIVENESS OF THE INTERVENTIONS

Student Performance

The effectiveness of the additional support measures was gauged both in terms of feedback from students and in terms of student performance over the year. Twenty students out of over one hundred from the Department of Electronic and Electrical Engineering were eligible to be invited on the pre-sessional course; the highest mathematics qualifications of these students were in BTECH, AS Level and GCSE mathematics (seventeen of these twenty students went on to start the degree course). Of these twenty students, eleven chose to attend the pre-sessional course. Reasons for students choosing not to attend the course included, receiving the invitation at too short notice, taking a year out, the attitude that their standard of mathematics was sufficient as to not to need to attend the course. Figure 1 below shows the performance of students, with non-traditional mathematics backgrounds in their first year mathematics module. The type of support received by these students is also indicated.

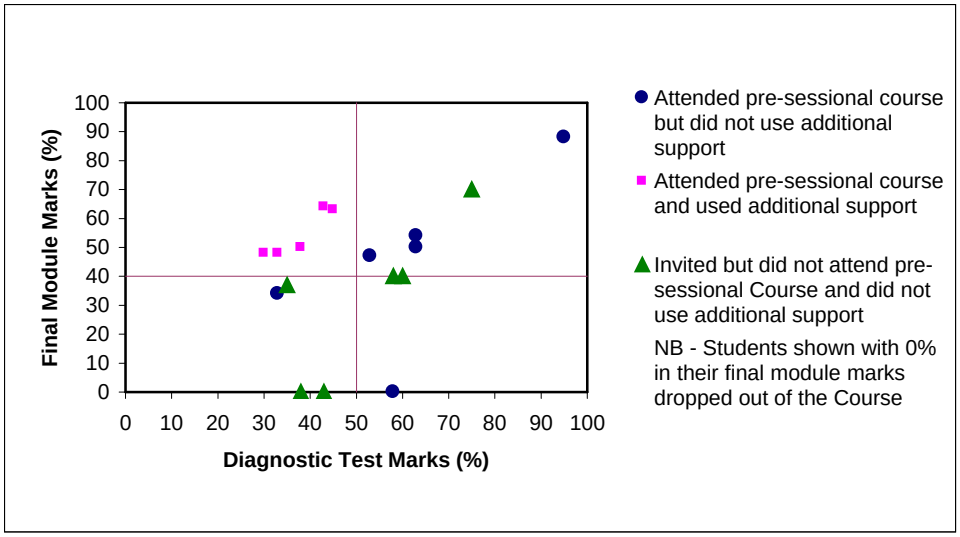

FIGURE 1
PERFORMANCE OF STUDENTS WITH NON-TRADITIONAL MATHEMATICS BACKGROUNDS: EFFECTIVENESS OF INTERVENTIONS

The chart shows that, of the seventeen students with non-traditional mathematics backgrounds that started courses in the Department of Electronic and Electrical Engineering in 2003, nine achieved less than 50% on the diagnostic test. Of these nine students, the three that did not attend the pre-sessional course chose not to accept any form of additional support and subsequently went on to fail the module. Only one student who attended the pre-sessional but failed the diagnostic test refused additional support, he also went on to fail. Four out of the five students who failed the diagnostic test but who had attended the pre-sessional accepted additional support. All four went on to pass their mathematics module. Students that passed the diagnostic test went on to pass the module with out additional support (it is not known if these students used the other forms of support offered by the Mathematics Learning Support Centre).

From this data it appears that performing well on the diagnostic test is a good indicator that a student will pass the mathematics module without the need for additional support. Further more, the data appears to suggest that students who have been on the pre-sessional course are more willing to receive support than those who have not been on the course; those students who received support went on to do well. This may indicate that the pre-sessional course is effective in giving weak students an awareness of and confidence in seeking additional support. However, it is possible that these results are a reflection of student motivation; those students who are willing to attend the pre-sessional course are also willing to work on their mathematics outside of timetabled lectures and coursework. Despite this, it does appear that the additional support on offer is effective in helping weak students address areas of weakness that would otherwise impede their performance.

Table 1 shows the average performance of students, who did and did not attend the pre-sessional course, against average class performance. The data shows that whilst both sets of students with non-traditional mathematics backgrounds performed below class average in their final module mark, the average of students who had attended the pre-sessional course was only 3% below class average as opposed to students who had not attended the pre-sessional course who were 11% below. If the final mark averages are examined only for those students who performed badly on the diagnostic test (see Table 2), then the students on the pre-sessional course, on average, performed better by the end of the year than the students who did not attend the course, whether than they had done A Levels or not. These findings suggest that the additional support is having a positive impact on student performance.

Type of Student (Numbers – Excluding Dropouts)	Average Marks		
	Diagnostic Test (%)	Coursework Tests (%)	Final Module Mark (%) (Excluding Dropouts)
Pre-sessional Course Attendees (10)	51	83	55
Invited but did not Attend (5)	52	74	47
Class Average (110)	66	75	58

TABLE 1
PERFORMANCE COMPARED TO PEERS: STUDENTS WITH NON-TRADITIONAL MATHEMATICS BACKGROUNDS

Type of Student (Numbers – Excluding Dropouts)	Average Marks	
	Diagnostic Test (%)	Final Module Mark (%) (Excluding Dropouts)
Pre-sessional Course Attendees Who Achieved Less Than 50% (6)	36	49
Invitees who did not Attend and Who Achieved Less Than 50% (1)	39	37
Students with A Levels Who Achieved Less Than 50% (24)	37	43

TABLE 2
PERFORMANCE OF STUDENTS WHO ACHIEVED LESS THAN 50% IN THE DIAGNOSTIC TEST

Student Feedback

Response from students engaging in the support activities has been positive. On the last day of the pre-sessional course students were asked to give feedback on how they found the course and its activities. Typical comments received included "excellent, helped me get back into the flow of doing maths again" and "helped boost my confidence in working with other people". Comments received about the course are summarised in Table 3. At the end of their first year, students were again asked to provide feedback on the pre-sessional course. Again feedback was positive. One student commented, "I appreciated the help as I felt I was behind everyone else, who seemed to have studied A-Level maths. I also met many other people in the same position as me, which really lifts your spirits."

Course Category	Feedback
Overall reaction to the course	The course was great. Not only does it help with the maths but also it appears to be a useful lead into university life. The course demonstrated well the back up available.
Mathematics sessions	Very good, helped me with things previously not understood. Excellent, helped me get back into the flow of doing maths again.
Team building sessions	Got us to know each other, make friends and have a good laugh. Helped boost my confidence in working with other people.
Q&A session with ex-engineering students	Excellent feedback. Interesting. Could be longer? Useful to know the real truth about the workload.
Oral presentation session	Scary! But good and helped us to learn how to improve our skills. Confidence Booster.
Time Management Session	Slightly repetitive of previous experiences but some new/useful information. Good to know where to get support. The time management kind of repeated what we already knew.
Museum Visit	Not as bad as it could have been but I would not go again. The tour was probably the most amusing thing we've done – for all the wrong reason.
Evening Entertainment	Top quality. Tour of Loughborough was also handy. Good!! Bowling was a good idea for a group activity
Food	The food was GREAT!! Lunch was a bit naff but evening and break were good.

TABLE 3
FEEDBACK FROM STUDENTS WHO ATTENDED THE PRE-SESSIONAL COURSE

With regards to the action plan support and workshops, student response to these measures has also been positive. Feedback from students regarding the action plan meetings suggests that students are encouraged to engage in self-study and are making use of the mathematical resources available to them. The following is a typical student comment, " I find the additional material that I work through during and between meetings valuable. It is also useful since I can bridge gaps in my knowledge and strengthen the maths I already know." In terms of the workshops, students find the flexible nature of the workshops attractive and appreciate being able to learn in a small group environment. "The best thing about the workshop was being able to take time to understand the subject, to stop the lecturer and ask questions." "The workshops consolidate what I know and help to address what is not clear to me". The following is a quote from a student who attended both the pre-sessional course and who also made use of the workshops and action plan meetings. "I was anxious when I was initially offered a place on the pre-sessional course, but looking back I now do not regret making the decision to go on it. It has been invaluable this year – if only to introduce me to the excellent level of maths support available to engineers at Loughborough."

Referring back to the rationale and aims of the three support measures it appears that these new measures are positively influencing students in the ways hoped. This is particularly true of the pre-sessional course where it appears to be successful in exposing and encouraging weak students to use the support facilities available to them at the University and in providing the students with an opportunity to network with students in similar situations. Despite the initial success of these new measures, lessons have been learnt which will influence the provision of these support measures in the future. These changes are discussed below.

LESSONS LEARNT

Both practical and strategic lessons have been learnt through providing these three support activities. With regard to the workshops it would be beneficial to increase the number of topics covered by the workshops and have them more closely parallel the engineering mathematics modules. Currently, topics in algebra and calculus are covered but the addition of matrices and complex numbers would be useful for students learning these topics for the first time in lectures.

In its first year of implementation, significant effort was put in to chasing students who performed badly in either their diagnostic test or coursework tests. It was found that students who responded to the initial offer of support were more motivated and committed to their action plans. Those students who only agreed to go on action plans after being offered support on a number of occasions tended not to continue with their action plans beyond these first four meetings. In this

respect it is suggested that individual targeting of students with the offer of action plan support is inefficient after the first attempt and subsequent reminders outlining the different forms of support available should be sent periodically to the whole student group.

In terms of the pre-sessional course a number of suggestions are made:

- In view of the data gathered, it may be beneficial to send all prospective engineering students, who do not have A Level mathematics, a mini diagnostic test for them to attempt. Invitations to the pre-sessional course should then concentrate on encouraging those students who performed badly on the test to attend the course.
- With the success of the pilot pre-sessional course it is suggested that intake to the course be widened to include students from other engineering departments and students whose A Level results were worse than expected but who have still been accepted onto their degree course.
- It has been suggested that students may benefit from the opportunity to spend longer working on their mathematics. Rather than run the course for longer, which would increase the cost of the course and the time commitment for students and staff, it has been suggested that the Algebra Refresher Workbook, which is used on the pre-sessional course, be sent to students in advance of the course. Motivated students could work through the book in their own time and could come to the course asking questions about topics that they struggle with.
- Providing a variety of sessions on the course is important, not only to make the course attractive to prospective students but also to break up the day. However it is important that these sessions are directly relevant to the students, either in terms of their degree course or in terms of their life at University. Some of the sessions provided on the pilot course were of engineering interest but had little relevance to aiding the success of the students whilst at University, such as the museum visit. It is suggested that this type of session be omitted from the programme and be replaced with more key-skill activities. This would directly benefit students in terms of the skills they need to perform well in their degree coursework.
- In terms of administering the pre-sessional course, the use of 'code of conduct' forms is strongly recommended. Although in the pilot course students were well behaved and attended all of the sessions, a signed form where students have agreed to abide by a set of rules could prove useful if students were less cooperative. A code of conduct form also impresses upon students the seriousness of the course and helps to discourage students from attending for the wrong reasons.

TRANSFERABILITY

Whilst the problem of students being unprepared for the mathematical demands of their course may be most prevalent in the UK, it is likely that other universities outside the UK will have similar problems, if perhaps on a different scale and with different causes. With respect to this the following provides an overview of the possible barriers and important elements for transferring these support activities to other institutions.

The support activities discussed in this paper are provided through the Mathematics Education Centre at Loughborough University. This centre houses the Mathematics Learning Support Centre, which provides staffed drop-in sessions where students from any department can receive individual help with their mathematics. The centre also houses a wide variety of mathematical resources on different media. Whilst the three activities discussed can be provided in isolation, there is value in providing them within the context of such a support centre; by providing a portfolio of support initiatives the mathematical needs of students can be addressed more holistically and a culture of mathematical self-improvement can be fostered.

Regardless of context, the provision of these support strategies is dependent upon time and financial resources. Activities such as the pre-sessional course and one-to-one action plan meetings are time intensive. Workshops are less so and impact a greater number of students than action plan meetings. It may be worth limiting action plan meetings to those students who struggle even in small group environments. With significant time required to organise the pre-sessional course it is perhaps most effective where other forms of support are offered by the institution; as exposing students to support facilities appears to be a significant benefit of the pre-sessional course. Having a dedicated member of staff to organise and oversee the running of the course helps to reduce time demands on other staff. If this member of staff is also to provide action plan support and other forms of mathematics support then the pre-sessional course has the added benefit of allowing the students to get to know the support officer, possibly making it easier for students to approach this person to ask for help in the future.

A second issue in transferring these support activities to other institutions is funding. Whilst an enthusiastic member of staff can run lunchtime workshops at little cost, a pre-sessional course requires a substantial source of funding. Currently students attending the pre-sessional course are not charged for the cost of the course, which for the pilot course was £205 (approximately $373) per student excluding staffing costs and £787 (approximately $1430) per student including staffing costs. Whilst increasing the number of students attending the course may help to reduce cost per student, it is important to

recognise the benefit, for the student, of working in small groups closely supported by a member of staff. In looking for sources of funding to run a pre-sessional course it may be necessary to promote the course to the engineering faculty, it is also worth considering making the course available to students on other courses with a significant mathematical content, such as economics and human sciences, and approaching these departments for funding as well. Students on the pilot pre-sessional course were surveyed about paying for the course; students overwhelmingly indicated that they would be willing to pay to attend the course. However, it is not known if students would be willing to pay the full amount.

CONCLUSIONS

In response to the growing numbers of students who are unprepared for the mathematical demands of their engineering course, the Mathematics Education Centre and Loughborough University has added to its existing methods of support. The new initiatives are designed to target students who have non-traditional mathematics backgrounds and who are likely to be at risk of failing or underachieving as a result of their possibly limited mathematics knowledge and skill. The three new support activities piloted by the centre in 2003 were aimed at first year Electronic and Electrical Engineering students and comprised a four-day pre-sessional course, action plan meetings with students who poorly performed on a diagnostic test, and optional lunchtime workshops. Different students preferred different forms of support. Results indicate that those students who performed badly on the diagnostic test but who had attended the pre-sessional course were more likely to engage in further support activities and go on to pass their mathematics module. It appears that student motivation is an important factor in passing the mathematics module. If sufficiently motivated and enabled by the support on offer, students who are initially mathematically weak are able to develop their skill and confidence. Other institutions looking to implement similar support activities are advised to seek out funding from their engineering departments and from other departments who may also have students that are impeded by their mathematical ability.

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