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Support for Students in their Transition to the First Year of an Engineering Degree

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The research presented here is a project to support students entering STEM degrees. The study aims to investigate and address the mathematical difficulties that many students present when making the transition to undergraduate Engineering courses. Data were collected on students' mathematical background, self-reported preferences in terms of preparing for assessments and outcomes on a mathematics diagnostic test. Both quantitative and qualitative methods were used to analyse the data, expanding the preliminary results reported in Treffert-Thomas, Hunsicker and Trott (2016). One of our findings showed that students without A/AS-level qualifications tended to use additional materials and online materials in particular more often than students with A/AS-level qualifications. This led us to develop an online, visual, dynamic resource aimed to be inclusive of all students including those with a learning difference.

Introduction and Background

In the UK, Advanced levels (or A-levels) are the traditional entry route for students to university degrees. However, many UK universities, including our institution, admit students presenting alternative qualifications such as BTEC (Business and Technology Education Council) diplomas or via the Foundation Programme. The Foundation Programme at our university is geared towards Science and Engineering degrees, accepts many students with BTEC qualifications, and has been very successful in providing a route for these students into the first year of a STEM degree.

It is from our experience of teaching students from such backgrounds that we have gained insights into students' mathematical preparedness. As Savage and Hawkes say, "There is strong evidence from diagnostic tests of a steady decline over the past decade of fluency in basic mathematical skills and of the level of mathematical preparation of students accepted onto degree courses" and "an increasing inhomogeneity in the mathematical attainments and knowledge of students entering science and engineering degree programmes" (2000, p.iii). Furthermore, there seems to have been little change over the ten years from then as Sheridan points out, "A continuing cause for concern in higher education institutions is the poor core mathematical skills of incoming students" (Sheridan, 2013, p.1). Hence, 'unpreparedness' of students for first year university mathematics, a core subject in Engineering courses, has presented significant challenges.

These challenges have been met by innovations and teaching and learning developments such as the setting up of the first mathematics support centre in the UK at our university (Croft, Harrison and Robinson, 2009). Mathematics support centres provide a system of support for all students who may struggle with the mathematical content of their course and are used by many first year students as well as our foundation students.

Looking particularly at alternative qualifications, Lawson (1995) found that there was little difference between students' overall end-of-year performance when presenting a BTEC or when presenting a failed A-level qualification (i.e., at grade N or U) upon entry. In addition, algebraic skills in particular were found to be weak for all students. We wanted to re-investigate the relationship between test performance and qualification in our current study, and consider also the resources that students reported using in their preparation for assessments while at school. Hence, in this study we have taken a fresh look at diagnostic test results, and their relationship to students' self-reported resource use and students' previous mathematical experience at school or college level. We aimed to develop a set of resources designed to help students from a variety of backgrounds. We also wished to be inclusive of dyslexic students, maths-anxious students and students on the Foundation Programme.

Method of Investigation

This was a study focused on our own university and our own students. We report from three stages of research. In Stage 1 we collected data from a diagnostic test that students took upon entry to the university and a questionnaire about students' mathematical background and self-reported preferences in terms of preparing for assessments. In Stage 2 we collected data from a screening test for dyslexia and a questionnaire about mathematical anxiety. In Stage 3 of the project we developed a set of mathematical resources.

Three different cohorts of students took part in the study. Table 1 shows the sample.

	Chemical Engineering	Electrical Engineering	Material Engineering	Total
Stage 1	137	150	62	349
Stage 2	16	19	14	49

Table 1: Research sample

In Stage 1 349 students completed the diagnostic test and 270 of these students also completed the questionnaire. In Stage 2 49 students self-selected to take the dyslexia test and complete the mathematics anxiety questionnaire.

Stage 1: Diagnostic Test and Questionnaire

The diagnostic test is a formative test taken by all Engineering students (including foundation students) in the first week of arriving at our university. The test covers 'number', 'algebra', and 'calculus'. 'Number' relates to topics such as standard form, fractions and decimals. 'Algebra' covers indices and solving equations, for example. 'Calculus' relates to differentiation and integration.

Students need good algebraic skills for their advanced work in calculus. We were therefore particularly interested in students' performance on the 'algebra' sections of the diagnostic test. The questionnaire about students' mathematical background was handed out in the first two weeks of the semester as students arrived for their lectures. It was aimed at obtaining demographic data such as students' age and gender as well as data in relation to students' pre-university study, namely qualifications and study habits. Here we use the term 'study habits' for how students reported on their preferred ways of revising for exams, using friends or family for support and help or online resources, for example. We were also interested in the highest qualification that a student held on entry to university.

Data from the diagnostic test and questionnaire were coded and entered into the statistical software R for statistical analyses. A combination of regression and clustering methods were used in the analyses. Qualitative data in the form of typed answers or written comments were analysed using qualitative methods of interpretation and coding.

There were 43 female participants and 226 male participants. 161 students presented with A-levels at grades A and B in mathematics. The number of students presenting each of the following mathematical qualifications were: A-level (206), AS-level (9), BTEC (14), Cambridge Pre-University qualification (1), Loughborough University Foundation Programme (8), GCSE (19), international qualifications such as CBSE, HKDSE, IB, INT (1, 1, 8, 2, respectively). 270 questionnaires were returned, but not all questionnaires were complete. In order to maximise the power of the statistical analysis, different subsets of the students were selected for analysis of each item on the questionnaire. The standard approach of multiple imputation was used to handle missing data. The imputation was done using the function and package 'mice' in R with the default five imputations. Quantitative results have been published in Treffert-Thomas, Hunsicker and Trott (2016) as well as analyses of some of our qualitative data.

Stage 1 Quantitative Results

Factors that Influenced a Student's Choice of Post-16 Study Route:

All students who participated in our study had entered university to pursue an Engineering degree. The analysis showed that age was most strongly related to a student's post-16 qualification with students in the two older groups less likely to have an A/AS-level qualification than younger students. Students who enjoyed the subject were more likely to have taken A/AS-levels as were those who had been encouraged to do so. We must be careful interpreting this, as enjoyment and being encouraged could be partially confounded here with performance at GCSE.

Trends in Study Habits and Relationship to Qualification and Test Performance:

The questionnaire was aimed at eliciting students' responses in relation to the type of materials they used when studying for assessments – we loosely refer to this as 'study habits'. Since the questionnaire was administered in the first two weeks of the university degree course, students' responses were taken to represent their 'study habits' at school or college level, and not at university level. Statements were formulated with 5-point Likert scales and focused on three areas: the use of printed materials, the use of online materials and 'in-person' help, such as from peers or family.

We will first summarise the data obtained. Students most frequently referred to "past examination papers" in preparation for a mathematics assessment. Over half the students reported that they used them every time that they studied for a mathematics assessment. Secondly students referred to printed notes such as “teacher-prepared handouts” or students’ own “written notes”, followed by mathematics “textbooks”. Almost all students reported getting “help from a friend”. When considering online materials in particular, we found that online videos were used most often, followed by “other online written” materials (not including online textbooks).

We next explored differences in students’ study habits using exploratory cluster analysis to determine if there were groups of students reporting significantly different use when studying for assessments. We extracted three clusters of statistically different study habits: the green, blue and red groups, as shown in the dendogram in Figure 1 ($p<0.001$). This represents the clustering of the students in terms of similarity of self-reported study habits, with the three large coloured areas representing the main three clusters. Participants who did not have A/AS-levels are represented by the cyan labels under the dendogram, whereas students with A/AS-levels are represented by the purple labels.

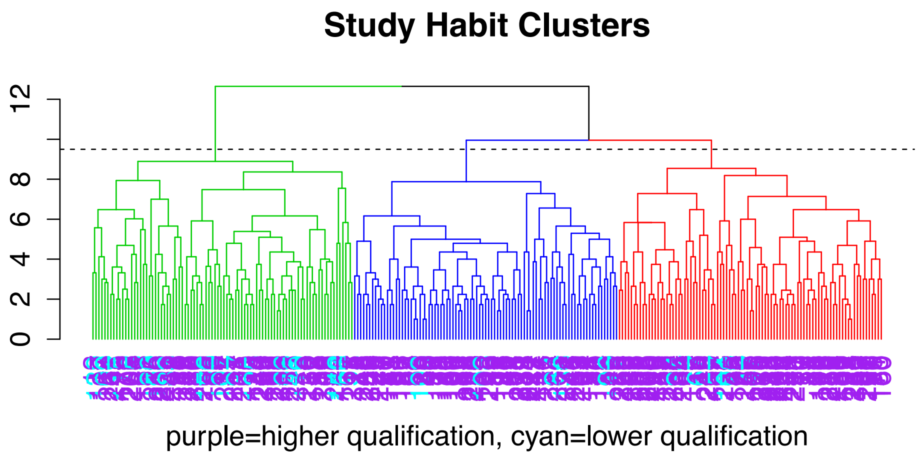

Figure 1: Students’ study habits

The clusters can be characterised as follows: The green cluster represents the ‘highest’ users of all types of materials, that is those students who self-reported using materials more frequently than students in the other two clusters. The red cluster represents students who used fewer materials altogether when compared with the other two clusters. The green and blue clusters used similar levels of ‘in-person’ help and printed materials, but the green cluster used more online materials. In particular, we found that there were highly significant differences among the clusters in their use of printed resources and online resources ($p<0.001$). There was no significant difference in students’ use of ‘in-person’ help (p-value of 0.1127).

We note from Figure 1 that the green cluster is the cluster containing the largest proportion of students without A/AS-level qualifications. This is important for the development of our set of resources.

Diagnostic Test Performance and Prior Qualification:

This part of the analysis was aimed at characterising research participants in terms of their performance on the algebra part of the diagnostic test. The algebra part of the diagnostic test was marked out of a total of 21 marks, with a mean of 14.58 and standard deviation 4.98.

When we considered test performance and qualification for different age groups (as shown in Figure 2) we found that older students tended to do better on the algebra test than younger students with equivalent qualifications. When we considered test performance and qualification by gender (Figure 3) we found that female students tended to do better on the algebra test than male students with equivalent qualifications.

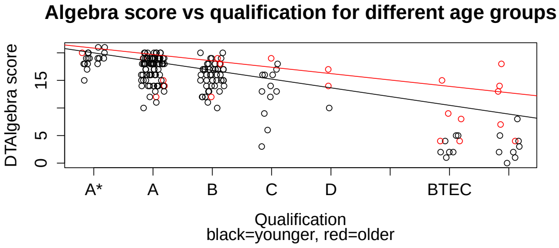

Figure 2: Test score, qualification and age group

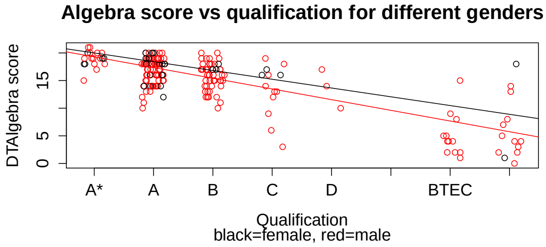

Figure 3: Test score, qualification and gender

We can see a substantial drop in algebra performance across the qualification levels. Students presenting a BTEC or GCSE as their highest qualification performed substantially worse than students presenting an A-level. This may be viewed as agreeing with Lawson (1995) who showed that students with non-traditional entry qualifications such as BTECs performed worse than students who had failed their A-level Mathematics (gaining a grade D or below). However, since we have few data points at grade D and none below grade D, comparisons with Lawson's extensive study are tentative and would require further investigation with larger data sets.

Stage 1 Qualitative Results from Questionnaire

Students were asked questions that related to their current university course. For example, students were asked about their motivation for applying for their particular course, their school experience and whether they had been encouraged to continue into the further study of mathematics. For some questions participants could provide a written comment. These data are our foci here.

Approximately one third of participants in each of the three cohorts provided additional written comments where these were possible. The comments were coded using an open-coding procedure that captured the content of student answers and then categorised them (Cohen, Manion and Morrison, 2008).

Students' Motivation for STEM Degree Study:

Table 2 shows the results for the question concerning what motivated students to apply for their course. Responses were assigned to one of five categories as tabulated below. Results are displayed in terms of the percentage of all responses within each cohort and in terms of actual number of responses (in bracket).

Category		Material Engineers	Electrical Engineers	Chemical Engineers
1	Career move	15% (3)	28% (13)	39% (22)
2	Looking to past experience	40% (8)	41% (19)	45% (25)
3	Looking forward to future	45% (9)	17% (8)	16% (9)
4	Enjoyment	0 (0)	7% (3)	0 (0)
5	Parental expectation	0 (0)	7% (3)	0 (0)
	All comments	**100% (20)**	**100% (46)**	**100% (56)**

Table 2: Students' motivation for STEM degree study (percentage and number of responses)

We can see that all three cohorts cited ‘past experience’ in approximately the same proportion. This relates to students expressing themselves in terms of their past study of mathematics, mainly at school level, where they had been “good at maths”, for example. For the Electronic and Chemical Engineering students this was the most frequently cited reason for choosing their particular degree. For Material Engineering students the subject matter itself appeared to matter most – both ‘looking forward’ to studying for their degree and, to a slightly lesser extent, ‘past experience’ during school. Chemical Engineering students cited career considerations proportionately more often than any of the other two groups and only a few percentage points less than past school experience. Earning potential and reference to “money” were often cited in the career context so that it may be a case of Chemical Engineering students thinking that their skills will attract higher incomes in the future, say in industry, including pharmaceutical industries, than other graduate engineering jobs.

Encouragement to Continue with A-level Study:

Anecdotal evidence and personal experience of teaching Engineering students has indicated that mature students often come into university study without formal A-level qualifications. We were therefore interested to find out if encouragement when at school played a role in students’ post-16 study routes. Table 3 shows the result to the questions, “Were you encouraged to take A-level Mathematics?” and “If yes, by whom?” Results are again displayed in terms of the percentage of all responses within each cohort and in terms of actual number of responses.

Category		**Material Engineers**	**Electrical Engineers**	**Chemical Engineers**
1	Self-motivation	58% (7)	29% (4)	79% (22)
2	School organisation	0% (0)	29% (4)	11% (3)
3	Choice influenced by prior attainment	8% (1)	14% (2)	4% (1)
4	Choice influenced by future career	17% (2)	7% (1)	7% (2)
5	Discouragement	17% (2)	21% (3)	0% (0)
	All comments	**100% (12)**	**100% (14)**	**100% (28)**

Table 3: Students’ responses on being encouraged or not (percentage and number of responses)

Self-motivation was cited by all three cohorts. This relates to comments of the kind “I decided myself” or “I always wanted to do maths”. The Chemical Engineering students cited self-motivation far more often and proportionately higher than the other two groups. A Chemical Engineering degree (at our university) relies heavily on students having a good grasp of mathematics, and more so than the other two Engineering degree courses. It is possible that students anticipated that they needed to take A-level Mathematics and to do well in it, and that anyone not motivated enough to try to get a high grade in Mathematics may have chosen a different degree from the start. So self-motivation may be masking ‘a need’ to do maths (and do well in it) rather than ‘wanting’ to do it.

No comment related to a teacher, parent or peer encouraging a student into A-level study. School organisation related to comments about the structure and choices that a school made available to students, the rationale that only the highest achievers were ‘allowed’ to take up A-level Mathematics, for example, or making a mathematics A-level compulsory for students taking one of the sciences at A-level.

There were five responses that we classed as 'discouragement from continuing into A-level study of mathematics'. The fact that capable students had been discouraged, in our view warranted further analysis. We, therefore, considered these students' profiles in more detail. Two students presented a GCSE qualification grade C and two or three BTEC qualifications as their highest qualification for university entry. Three students (all taking an Electrical Engineering degree) presented an A-level Mathematics despite having been discouraged when at school. One of the students wrote, "I was advised against it" [studying for an A-level in Mathematics]. There is not enough information to draw definitive conclusions. However, these students' recollections fit with our experience of schools that tend to encourage only their very best students (GCSE grades A and A*) to progress to A-level Mathematics.

Stage 2: Dyslexia Screening Test and Mathematics Anxiety Questionnaire

Stage 2 consisted of a screening test for dyslexia using the LADS software (Lucid, 2015), and of a mathematics anxiety questionnaire (Hunt et al., 2011). Students self-selected to take part and 49 students participated. The screening took place with a specialist dyslexia tutor who could offer advice in cases where a student was found to be either 'at risk' of being dyslexic or indicated being maths-anxious.

The LADS (Lucid Adult Dyslexia Screening) software is a computerised test designed to screen for dyslexia in persons of 15 years and older. It assesses responses to a variety of questions in the areas of non-verbal reasoning, verbal reasoning, word recognition, word construction and working memory. The test creates an individual profile indicating whether a participant is likely to be dyslexic.

The mathematics anxiety questionnaire (M.A.R.S. – Mathematics Anxiety Rating Scale) consists of a series of statements concerning situations that involve mathematics. Participants answer on a 1-5 Likert scale on how anxious the situation described made them feel, from 'not at all' (1) to 'very much' (5). Responses were, of course, subjective. There were 23 statements altogether, taken directly from Hunt et al. (2011). The scores could range from 23 to 115.

Of the 49 students who took part in Stage 2, eight students were found to be 'at risk of being dyslexic'. This assessment was provided by the computer-generated LADS profile. The mathematics anxiety questionnaire yields a single score which was used for comparison with our data sets on encouragement and resource use. The higher the score, the more anxious a participant was deemed to be. Our data ranged from 23 to 68 points with four students scoring 60-68 and eight students scoring 50-59. The remaining students scored under 50.

Stage 2 Results: Dyslexic Students and Maths Anxiety/Resource Use

Comparing dyslexic students' responses on the maths anxiety questionnaire and Stage 1 data, we found that:

1. Dyslexic students were more maths-anxious than their non-dyslexic peers by around 10 points on the maths anxiety scale.
2. Dyslexic students used different types of materials (paper-based, person-based and online) on average 1.5 times more often than non-dyslexic students; it was noted that they particularly sought in-person help from family, friends, tutors, etc.
3. There were no differences between dyslexic students and non-dyslexic students in terms of encouragement to study and enjoyment of study.

Comparing mathematically-anxious students' responses with Stage 1 data, we found that:

4. Mathematically-anxious students tended not to enjoy their study of mathematics (although results were marginal).
5. Students at the upper end of the maths anxiety rating scale had a tendency to seek in-person help more often than students at the lower end of the scale; this is despite there not being a difference between these students in relation to overall material use.
6. There were no differences between anxious and non-anxious students in terms of encouragement and overall material use.

The results summarised above were based on a relatively small sample. There were 349 students who took part in Stage 1. Only 1 in 7 students from Stage 1 also took part in Stage 2 so that the number of dyslexic students was expected to be small. This is inevitably the case when collecting data in just one institution and among a limited number of cohorts of students. In addition, students self-selected to take part in the dyslexia screening – an ethical consideration. However, the eight cases present eight case studies that are informative.

Results from both Stage 1 and Stage 2 were used to inform the kind of resources that we wanted to design – with dyslexic students and maths-anxious students in mind as well as students who did not have traditional A-level Mathematics qualifications.

Stage 3: Development of a Set of Resources

In this stage of our study we developed a set of resources on four topics relevant to first year engineering mathematics: differentiation, integration, matrices and complex numbers. These resources were developed for use online as indicated by results from the Stage 1 questionnaire – a larger proportion of BTEC students favoured using online materials when revising for exams. The resources were designed to be dyslexia-friendly.

Each of the four resources we developed took the form of a 'mind map' or 'concept map', a visual representation of the topic. We obtained some qualitative feedback from first year Engineering students. We believe our set of resources is inclusive of all students, including those with an additional need. Below we show screenshots of the resource interface (at various points) as the student interacts.

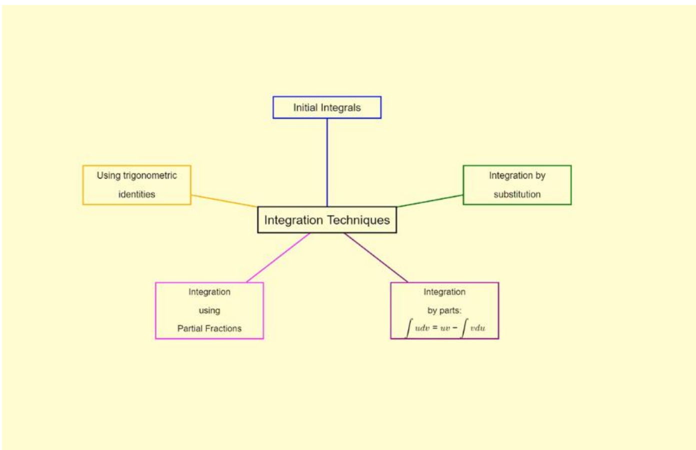

Figure 4: Initial layout of the integration resource

Figure 4 shows the initial layout of one of the resources – as a mind map or a spider diagram. As the student clicks on a topic to revise, a second level of categories appears. However, all original categories remain visible on screen as shown in Figure 5.

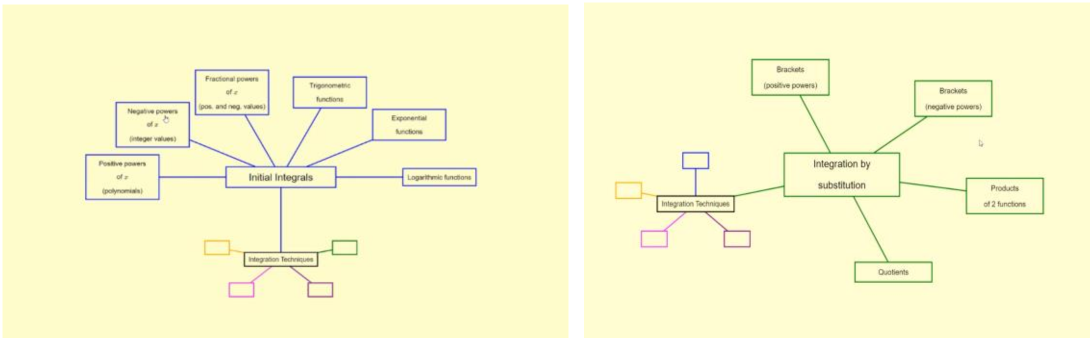

Figure 5: Examples of a second layer of categories

The student can then choose to revise a particular topic and in turn will see a number of questions to attempt. Answers are hidden and can be 'revealed' by a click of the mouse button (see Figure 6). We wish to stress that all original categories are still visible on screen (having moved sideways and reduced in size) with colour-coding allowing the student to keep track.

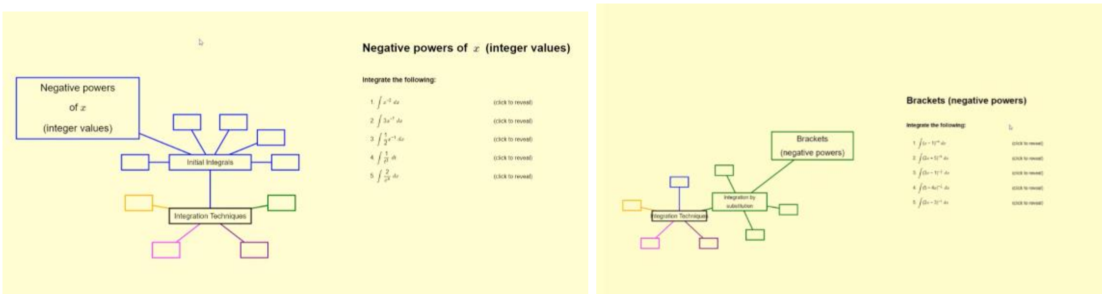

Figure 6: Examples of a set of questions

Summary and Conclusion

We used quantitative and qualitative analyses which provided some useful and complementary results.

From Stage 1 analyses we found that students with a BTEC qualification performed worse on the 'algebra' section of the diagnostic test than students with an A-level. While this cannot be compared with the findings of Lawson (1995), we found the substantial drop in performance by students from non-traditional mathematical backgrounds worrying. It made us consider that after twenty years not much has changed in this position. We explored additional student characteristics and found three clusters of revision material use. Within these clusters we found that A-level students' use was 'light' and based mainly on printed formats, while students with BTEC or similar qualifications accessed online materials more frequently, and materials in general more frequently than any other group.

From the qualitative analyses in Stage 1 we found that all three cohorts of Engineering students cited a positive experience of school mathematics as a major reason for choosing their field of study. Chemical Engineering students cited career aspirations and earning potential more frequently than other students. We conclude that the image of engineering in the wider world may have played a role in influencing degree choice.

There were few written responses to questions about encouragement so that our findings here need to be interpreted with this in mind. Five case studies, although small in number, highlight that some students did take A-level Mathematics despite having been discouraged. This could be viewed in relation to evidence provided in Matthews and Pepper (2007) showing that there is a need to target a wider group of students and that for increased uptake of A-level Mathematics participation "would need to become less exclusive" (ibid. p.6). We see foundation programmes as playing a vital role in access to Higher Education in this respect.

Results from Stage 2 showed that dyslexic students tended to use revision materials 1.5 times more often than their non-dyslexic peers. Responses from mathematics-anxious students indicated no difference in overall use of revision materials when compared with their less anxious peers.

Guided by the above results, we created a set of resources that was designed to be inclusive of all students who enter Engineering degrees at our university, i.e., students without A/AS-level Mathematics qualifications, dyslexic students and students completing the Foundation Programme. The resources were designed for use online. In order to help students who struggle with sequencing (as dyslexic students often do), the content of each topic is displayed on one screen that moves dynamically as the student works through the mathematics. Thus interrelationships in mathematics are highlighted, which we know from experience to be beneficial for dyslexic students as indeed for all students.

The set of resources has been well received by staff during Learning and Teaching events at our university. Non-maths staff were able to see how the resource could be applied and used in their own subject area. This has encouraged us to consider a more generic template for such use.

There is a continued demand for graduates with quantitative skills in the UK economy (e.g., Truss, 2011). The demand for extra UK graduates with quantitative skills, at present, will have to be met by recruiting students without, or with lower grades in A-level Mathematics. More long term strategies are needed to encourage students to take up A-level Mathematics at age 16 or, alternatively, to create pathways so that students with lower qualifications do not find themselves excluded from an advanced level of mathematical study (Matthews and Pepper, 2007).

We know from our experience of teaching students at our own institution that students with alternative qualifications such as BTECs are interested in pursuing mathematically demanding engineering courses. Engineering departments and universities as a whole have much to gain in recruiting these students. We believe alternative academic pathways that lay a solid mathematical foundation and prepare students for engineering degree study are important and necessary.

Finally, while this study was with first year Engineering students, much of what we learnt is directly relevant to other foundation programmes. Our institution recruits over 180 students to the Foundation Programme, mainly for STEM subjects. Many students lack good mathematics qualifications, having instead A-levels in other subjects or BTECs.

Acknowledgments

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