Increasing the Impact of Mathematics Support on Aiding Student Transition in Higher Education

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The ever growing gap between secondary and university level mathematics is a major concern to higher education institutions. The increase in diversity of students' background in mathematics, with entry qualifications ranging from the more traditional A-level programmes to BTEC or international qualifications is compounded where institutions attempt to widen participation. For example, work-based learners may have been out of education for prolonged periods, and consequently, are often unprepared for the marked shift in levels, and catering for all abilities is difficult in the normal lecture, tutorial format. Lack of sufficient mathematical knowledge not only affects students' achievement on courses but also leads to disengagement and higher drop-out rates during the first two years of study. Many universities now offer a maths support service in an attempt to overcome these issues, but their success is varied. This paper presents a novel approach to maths support designed and adopted by the University of Lincoln, School of Engineering, to bridge this transition gap for students, offer continued support through assessment for learning (AFL) and Individual Learning Plans (ILP's), and ultimately increase student achievement, engagement and retention. The paper then extends this proven approach and discusses recently implemented enhancements through the use of on-line diagnostic testing and a 'student expert' system to harness mathematical knowledge held by those gifted and talented students (often overlooked by higher education institutions) and to promote peer-to-peer mentoring. The paper shows that with the proven system in place, there is a marked increase in student retention compared with national benchmark data, and an increase in student engagement and achievement measured through student feedback and assessments. Although the on-line enhancements are in the early stages of implementation it is expected, based on these results, that further improvements will be shown.

Keywords: Mathematics support; Engineering; diagnostic testing; Assessment for learning; Student mentoring; Transition.

1. Problem Definition

Since 1990, it has been well known that the level of mathematical knowledge of students entering higher education has declined and that this shortfall not only impacts on their success but also significantly affects student engagement and retention. Around 28,000 full-time and 87,000 part-time students who commenced their studies in 2004-2005, were no longer in Higher Education in 2005-2006. A review of mathematics education carried out by Sir Gareth Roberts in 2002 [1] showed that students can experience difficulty in making the transition from A-level to degree level and this not only has an impact on student success but also impacts on the number of students opting for technical disciplines at universities. With the known huge shortfalls in students opting for STEM subjects and, in terms of engineering, an estimated requirement for around 220,000 undergraduates between 2007 and 2017 [2], the need to put effective measures in place to aid this transition is now hugely apparent.

These considerations are at the forefront of thinking in subjects with some level of advanced mathematical content, and many institutions now have a maths support system in place, albeit with varying degrees of effectiveness. Universities do recognise that students are entering higher education with a lower level of basic mathematical skills, but should also recognise the ever-increasing diversity in cohorts, from students who have studied more traditional A-level's to those with BTEC and international qualifications, and part-time students from industry, and how this requires a more structured approach to mathematics support. With the government's increasing focus on channelling students through the vocational qualification route [3], the potential for universities to lower entry requirements to meet the demands of the rise in tuition fees, and with industry keen to develop its workforce in order to compete within global markets, the need for more effective mathematics support will become more significant over the coming years.

2. Background

In a 2001 study [4], a total of 95 UK Higher Education Institutes were asked if they provided any kind of maths support. Out of these 95, 46 indicated that they provided maths support whilst 49 indicated that they did not. "*The key element of this provision, which was identified most often by respondents, was the availability of one-to-one support*." This study was updated in 2004 and it was noted that out of 106 UK Universities, 35 still did not provide mathematics support [5]. The latest study [6] published in 2012 identified that out of 103 institutions, 88 had some form of maths support programme which is very encouraging.

Engineering disciplines are underpinned significantly by mathematics, and a lack of knowledge in the basic mathematical skill areas has a profound impact on student success. It was found that students who lacked basic mathematical knowledge, and in particular part-time students who had achieved the entry requirements but who had not studied for many years, were much more likely to not only underachieve in standalone mathematics modules, but also in the other modules such as Thermodynamics, Mechanics and Dynamics [7]. This lack of understanding has the potential to force students to focus on grasping and improving their fundamental mathematical knowledge alone, often leading to disengagement in subjects where mathematics is essential but misunderstood and ultimately, to poor achievement and retention.

Problems associated with a fundamental lack of mathematical understanding are experienced across the sector, and to some extent, across the globe. Many universities have put maths support systems in place, for example, by the way of drop in centres, extra lectures, maths clinics, publishing self-directed study materials, but problems persist. For example, Mac An Bhaird [8] noted that the majority of students who were identified as having significant difficulties chose not to attend a centralised maths support centre, and within science subjects, only 33% of the at-risk students attended more than once (see also [9]). Similarly, Patel and Rossiter [10] noted that 40% of engineering students did not know there was a central maths support service within their institution, and 54% knew of the service but didn't use it.

So, the question is, how do we continue to provide and develop these mathematics support strategies in a way that provides individual students, with very diverse backgrounds in both mathematics and engineering, with the best chances of success? This is a question that this paper seeks to (at least in part) address.

The Lincoln School of Engineering, University of Lincoln, UK, was founded in November 2009 in close collaboration with Siemens Industrial Turbo-machinery Ltd. It is the first purpose-built University Engineering facility in the UK for more than 20 years, with an overarching goal to establish a Centre of Excellence for industrial power and energy engineering, higher education and research. Due to collaboration with Siemens and a drive to produce 'industry-ready' graduates, the School enrols students from a wide-range of backgrounds, including a significant number of part-time students, students from vocational backgrounds such as those with BTEC qualifications, international students and students with traditional A-level's. The inherent diversity in these student cohorts' means that the transition from further to higher education can be difficult to achieve smoothly and hence the need for a structured and novel approach to support this process. For this reason, the School chose to prioritise the establishment of an effective mathematics support system that would provide the initial support to students during the early stages of their degree programmes, but would also continue to be available throughout their study. The mathematics support is very much tailored towards individual student's needs without the demands of providing literal one-to-one support.

3. 'Bridging the Gap' – Transition Support

A key question when faced with delivering material at any level is, "what fundamental knowledge will the students need during its delivery and how can we check if they already possess that knowledge?" This is frequently achieved to some degree through the use of a mathematics diagnostic test that students are required to complete prior to the start of their first academic year. However, three problems often arise from this approach. Firstly, the content of the diagnostic test is often not thought through adequately, and the only question it achieves in answering is how strong (or not) a student may be in basic mathematics and not even necessarily the basic mathematics that they require. Secondly, the test results are not used to inform any sort of learning plan for students meaning that valuable information about students' mathematical knowledge is not put to best use. Thirdly, students are often asked to take a diagnostics test without any preparation and this very alien experience may bias the test scores. This paper begins by detailing a much more structured and informed approach that attempts to address and extend two of the recommendations set out by the UK Engineering Council [11] that states the following as key recommendations:

1. Students embarking on mathematics-based degree courses should have a diagnostic test on entry.
2. Prompt and effective support should be available to students whose mathematical background is found wanting by the tests.

In the approach used at Lincoln, the content of the diagnostic test is driven by fundamental mathematics skills required for the students first year of studies, both in terms of stand-alone mathematics modules and other core disciplines. These topics are not on the syllabus as discrete subjects and are not topics that time necessarily allows to be covered in lectures. For example, the study of vector algebra relies heavily on knowledge of basic trigonometry ratios, or the study of partial fractions relies on polynomial division, therefore, the diagnostic test focuses on trigonometry rather than vector algebra and polynomial division rather than partial fractions. Through careful selection of the content, the diagnostic test provides a much more informed picture of, and insight in to, students' mathematical knowledge. Content is selected through examination of all first year module specifications, identification of required mathematical skills and then separation into fundamental and taught components. The diagnostic test is then based on these fundamental areas. The results of the diagnostic are used to design Individual Learning Plans (ILP's) for students who showed weaknesses in these fundamental areas, and the ILP includes the opportunity of specific targeted mathematics support sessions to address these weaknesses, rather than uniform attendance on a general programme. This tailor-made approach avoids the pitfall of assessing to a threshold where only the students falling below some particular score level receive targeted support. The use of ILPs means that areas of improvement and hence opportunities to support learning can be offered to all students, including those who would have been neglected by a threshold process. Anecdotal evidence has shown that, for Lincoln students, this method has had a profound effect on their confidence, and has allowed students to focus on the main delivered material rather than being hindered by their lack of underpinning mathematical knowledge. Figure 1 below shows an extract from a typical ILP for two students with key priorities identified.

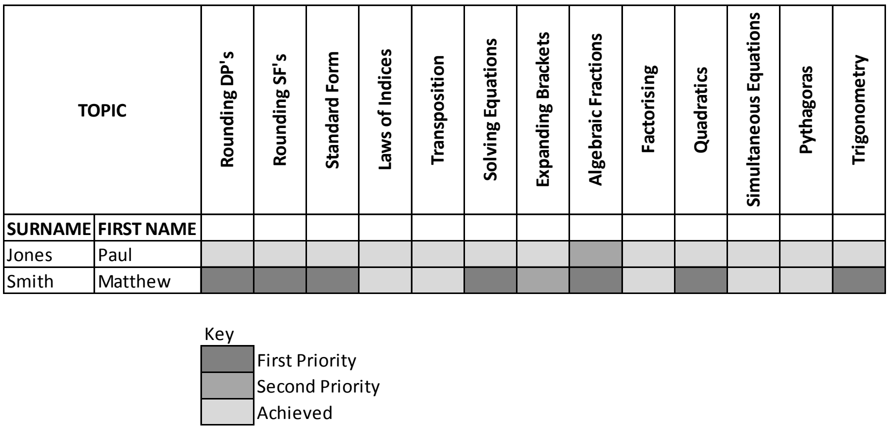

FIG. 1. Extract from typical student ILP

4. Continued Support Through Assessment for Learning (AFL)

Following the results of the diagnostic test and the implementation of ILP's for students, Lincoln avoids the temptation to treat this as a 'tick in the box' exercise and leave students to their own devices for the remainder of their studies, only to find that they fall short in other areas of mathematics at a stage when it is virtually too late to intervene. The approach adopted by the Lincoln School of Engineering addresses this issue through the use of Assessment for Learning (AFL).

AFL is a strategy adopted mainly in Schools to inform student's learning and to improve the rate at which students' progress. "*Assessment for learning is the process of seeking and interpreting evidence for use by learners and their teachers to decide where the learners are in their learning , where they need to go and how best to get there*" [12]. The strategy outlines 3 major aims that are readily transferable to the way assessment is approached in Higher Education:

- Each student knows how well he or she is performing, they understand what they need to do to improve, and they know how to make that improvement. In order to achieve this they must have the correct support in place.
- Every lecturer is equipped to make well-founded judgements about students' attainment, they understand the concept and principles of progression, and they know

how to use their assessment results to forward plan; particularly for students who are not fulfilling their potential.

- Every institution has structured assessment systems in place that are used to make regular, useful, manageable and accurate assessments of student learning, and for tracking their progress.

The mathematics support approach adopted at Lincoln pays particular attention to these points in terms of assessing students' progress, making students aware of what is required of them and putting the correct measures in place to ensure that they are given adequate support to enable them to not only make progress, but to be able to identify for themselves that they are continuously improving.

The progress of individual students is monitored by teaching staff during lectures and tutorial/seminar sessions using well known AFL techniques such as explicit learning objectives, random questioning, immediate student feedback, and levelled exam style questions, i.e. where students are provided with questions targeting different levels of thinking skills, in-line with Bloom's taxonomy and hence degree classifications, for example solving a second-order ODE (knowledge/understanding) or solving a mass-spring-damper system using ODE's (application). Students' ILP's are continuously updated by teaching staff and followed up by targeted invitations for students to attend the relevant and appropriate mathematics support sessions, consisting of weekly timetabled sessions designed to focus on specific topic areas. This approach allows the individual student to not only identify the level that they are currently working at but also to see what is required in order to reach the next level. This in turn improves understanding and success within mathematics and other core disciplines.

5. Evaluation of the Current System

The effectiveness of this approach has been measured in relation to three areas; achievement, engagement and retention. The overall impact can be readily measured through retention data but achievement and engagement have a large influence on this primary measure. Comparisons have been made between the data for the Lincoln School of Engineering, for 44 first year students, and the KIS Engineering Benchmark Data; see figure 2.

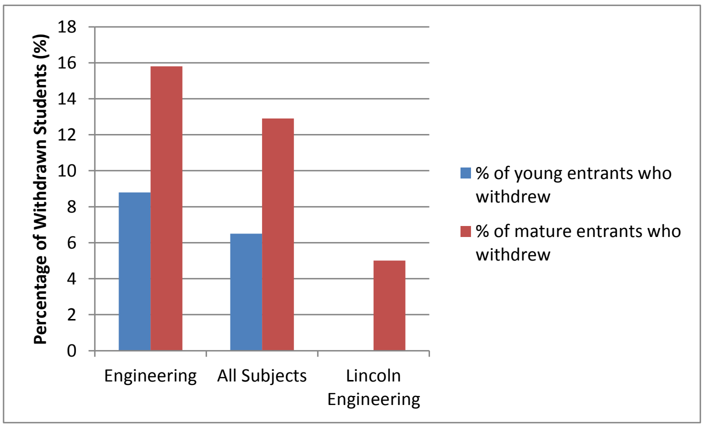

FIG. 2. Comparison of retention data.

It was found that the percentage of young entrants to full-time degree courses in 2008-09, who withdrew from their studies, was 8.8% for engineering courses compared to 6.5% for all subjects. This included students with significantly higher entrance qualifications than our own entrance qualifications equivalent to 280 points. Our retention rate in this category was 100%, i.e. all Lincoln Engineering students continued with their studies. This picture is also reflected more graphically among the percentage of mature entrants to full-time degree courses in 2008-09. Within this category, it was noted that 15.8% of mature engineering students abandoned their studies compared with 12.9% for subjects overall. At Lincoln, the percentage of students who withdrew was only 5%. Student achievement is backed-up by these retention figures. Of the students who withdrew, 100% had achieved sufficiently high scores to progress, so their decision to leave was not motivated by under-achievement.

The impact on achievement has been measured through the analysis of correlation between diagnostic and exam results. Results from the initial diagnostic test for each student have been correlated against the result from their first year maths examination. The results were analysed for 3 categories of students:

1. Students who were identified as needing minimal maths support, i.e. for purpose of comparison only, those that achieved above 70% in the diagnostic.
2. Students who were identified as needing maths support and made use of the support offered.
3. Students who were identified as needing maths support but who failed to make use of the support offered.

The support offered consisted of a 3 hour weekly timetabled session focusing on specific topics as identified by each student's ILP. Those who engaged in the support process were considered as those students who attended all of their respective sessions.

A total of 44 students, including 36 full-time and 8 part-time students, were considered in the analysis. For clarity, 2 outliers were removed from the data set giving 26 students in category 1, 10 in category 2 and 6 in category 3. Correlation is measured using the Product Moment Correlation Coefficient,

$$R = \frac{\sum xy}{\sqrt{\left(\sum x^2\right)\left(\sum y^2\right)}}, \text{ where } x = X - \overline{X} \quad \text{and} \quad y = Y - \overline{Y}$$

Figure 3 shows the correlation between diagnostic and exam results for each category of students.

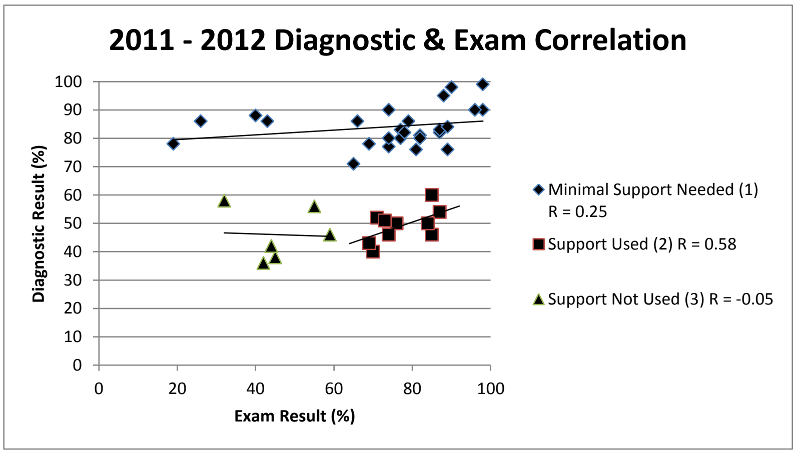

FIG. 3. Correlation between diagnostic scores and exam results.

The results of this analysis indicate that there is direct correlation between diagnostic and exam results for those students in category 2, whereas performance in the other categories is very mixed. For students identified as needing minimal support (category 1), although support was still offered, their understanding of the fundamental skills, as identified by the diagnostic test, enables good progress in the taught material and ultimately good exam results. For the students identified as requiring and making use of the support (category 2), although their initial diagnostic scores were similar to those students who were identified but did not make use of the support (category 3), their final exam results show a marked improvement. For the group of students who decided not to engage in the support process, their lack of understanding of the fundamental skills, again identified by the diagnostic test, seriously impedes their progress in the taught material leading to poor exam results.
Student engagement has been measured through regular student feedback facilitated through the use of feedback forms administered to students once per fortnight – an intensive process, but a necessary one during the start-up phase of a new School of Engineering. The feedback gained from students showed that subjects underpinned by mathematics received high scores in the areas of understanding and interest. This level of satisfaction was confirmed within discussions between students and their personal tutors as well as academic tutors. Anecdotal evidence showed that students increasingly reported that their underlying knowledge of the fundamental mathematical principles continually improved with further engagement with the maths support system, and that this allowed them to focus their studies on the material being taught.

6. System Enhancements

The current system, as described previously, is highly successful, but may be difficult to sustain as School and cohort sizes grow; current first year cohorts consist of around 50 students. To this end, a series of system enhancements have been identified and recently implemented. The enhancements build on the current system, and continue to allow for accurate assessment both in terms of initial and continued diagnostic testing. The enhancements serve as a method of identifying the sustained support requirements of individual students throughout their studies. The implementation allows this maths support methodology to become robust enough to engage students studying on any programme with mathematical content across the whole institution rather than just within the School of Engineering.

6.1 On-Line Diagnostics

Traditional AFL strategies have been designed around group sizes of approximately 30 learners, which would typically be found in a school or college environment. Although these can still be implemented on a larger scale within typically larger HE class sizes, their effectiveness in individual assessment begins to diminish and they become very labour intensive. For example, it is quite appropriate to use levelled exam questions with varying degrees of difficulty at the end of a teaching session to check the level and understanding of 100 students in a particular topic, but to do this throughout the year, where maybe twenty topics are covered, becomes unmanageable, and the amount of tutor time spent in marking and providing feedback could mean that the technique becomes counterproductive – particularly if feedback and test scores are delayed. It is possible to obtain an overall picture of student knowledge without this levelled technique, such as assessment by random questioning or against explicit learning objectives, but this doesn’t give a detailed summary

of every students' strengths and weaknesses, nor does it provide a mechanism for allowing timely feedback to students. The enhanced system uses on-line diagnostics as a way of tackling this problem.
The on-line diagnostics are a series of test questions designed to cover those topics as identified by the appraisal of fundamental skills discussed in section 3, along with a series of test questions covering new taught material, to provide information on initial and sustained support requirements. Questions are designed such that they match the topics that students can expect to come across in an exam situation and are separated into two distinct levels in order that students can assess themselves against these levels. Exams are typically broken down into a series of cascaded questions with varying levels of difficulty, where some require only knowledge and some application or synthesis of that knowledge, in line with Bloom's taxonomy [13]. Mathematics exams set by the School of Engineering are broken down into two distinct sections. Section A covers very generic questions such as integrating a function by parts or solving an ordinary differential equation. These questions require only knowledge of the process of integration or that of solving differential equations and require no application to a specific engineering problem. These are called Level 1 questions and would represent a pass standard within an examination. In order for students to gain marks worthy of the higher degree classifications, they must demonstrate that they can take this knowledge and apply it to a specific problem. In terms of integration, this may be finding a volume of revolution or, in the case of differential equations, analysing a mass-spring-damper system. This requires a higher-order skill according to Bloom's taxonomy and would therefore carry more marks, and these are referred to as Level 2 questions. To successfully implement AFL strategies it is important to not only identify students' weaknesses in specific subject areas, but also to provide targets to allow them to identify their own progress. These should be made available to all students, irrespective of their level of attainment. For example, student A completes a test on integration which covers both level 1 and level 2 questions. The test identifies a weakness in carrying out integration by parts, a level 1 question, and also finding a volume of revolution, a level 2 question. The primary target for this student would be to work on integration by parts as this is seen as a fundamental building block for the level 2 questions. Student B, however, is very able and scored very well in the level 1 questions but showed some weakness in the level 2 questions. This student's main focus would therefore, be on the level 2 questions. A robust system must cater for all students in the assessment process and provide targets for improvement for all abilities including those G&T students who are often overlooked.

Tests continue to be administered following each taught topic and students continue to be assessed against specific learning outcomes aimed explicitly at these two levels. This allows students to be informed of their current level and the work required in order to reach the next, whether this is full familiarisation with all level 1 questions or to encourage progression on to level 2. This information is contained within each student's ILP which is automatically and continually updated throughout their first year of studies. Support is offered via numerous on-line resources, through additional timetabled support sessions, or by a student mentoring system. The advantage of the on-line system is that students can be monitored in real-time during tutorial sessions meaning support can be offered immediately, reducing the risk of future problems with engagement in the support process.

6.2 Student Mentoring

There have been numerous studies around the effectiveness of student mentoring within higher education institutions, for example [14 and 15], and some forward thinking institutions are beginning to implement mentoring strategies as part of the overall strategy to improving retention and success of students. These tend to be focused on social issues as a way of helping students cope with the huge demands faced when embarking on their undergraduate studies, for example, the use of induction activities to help students familiarise themselves with the campus, or develop self-directed study techniques is widespread. Although these types of activity can be conducted by staff within an institution, it has been shown that they are much more successful when conducted as part of a student mentoring programme [16]. One of the main benefits of this type of arrangement is that second and third year students can share their experiences of student life with first year students in a much more meaningful way. This in turn builds closer relationships between students and gives a sense of belonging. Although these schemes have proven very successful in many institutions, there still remains a huge requirement for more subject specific student mentoring programmes. Student-to-student support in subject areas such as mathematics often occurs naturally within cohorts to some degree but this is rarely formalised and so it is not universally available. It must also be recognised that the benefits of second year students, who have already studied mathematics in year one, mentoring new first year students are substantial, often allowing support in areas that students themselves have found barriers to learning [17]. This can also act as a method of encouraging second year students to continually review first year taught material, which in turn promotes success.

Setting up cross-institutional support systems is also an area that has the potential to provide huge benefits, both in terms of social and academic interaction. Being able to gain support from a much wider range of students, studying on different courses with different approaches to learning, and with students exposed to numerous different teaching styles and techniques, has the potential to create a much more effective student mentoring system. Introducing subject specific mentoring systems also has the benefit of harnessing the knowledge of G&T students. To this end, Lincoln has developed a 'student expert' system as a way of formalising student-to-student mathematics support and encouraging cross-institutional interaction.

The student expert system is designed to achieve three main objectives.

- To harness the knowledge of gifted and talented students in providing student-to-student support.
- To promote support between first and second year students as a way of increasing success of not only first year students but second year students also.
- To encourage cross-institutional support.

The system identifies particular student strengths, either through the on-line diagnostic tests, based on previous study, e.g. for second year students, or by the student's own assessment. The students then become 'experts' in these areas. This information is used to generate a list of student experts from across the institution with the aim of providing several experts in each topic area. Student experts are provided with training prior to commencing their role to ensure the most effective support is offered to students. Upon completion of specific diagnostic tests, students are given the option to contact a student expert to gain support in areas of weakness. Support remains anonymous from the point of view of the student requesting support to prevent known negative effects of competition and effects on self-esteem. For example, Croft [18] reported that anonymity and confidentiality are serious concerns where an intervention is made for a student who is at risk of failing or withdrawing. A study conducted in relation to the impact of anonymous and face-to-face competition in a learning environment [19] showed that students who were exposed to anonymous competition responded significantly more positively than those in a face-to-face environment in terms of motivation and satisfaction. The study goes on to say that "*anonymity is a viable feature for mitigating the negative effects that competition may inflict on motivation and satisfaction as reported in traditional face-to-face environments.*"

A second issue that institutions often face in relation to student mentoring programmes is that of engagement. How do we inspire students to become mentors and how do we ensure they are fully engaged in the support they offer? The answer is relatively simple; competition and recognition. Although it has been shown [20] that competition has some negative effects in certain environments; such as in the case of students being made to feel inferior to other students in asking for face-to-face support; it can also have a positive impact. Students are much more likely to be engaged as mentors if they feel they are competing with other mentors to offer the best support possible and are being recognised as experts amongst peers. Belfield and Levin [20] conducted a study in 2002 to look at the effects of competition between schools on educational outcomes. They discovered that in the vast majority of cases there was a positive correlation between competition and educational quality.
Secondly, gaining recognition from both the student being supported, and the institution as a whole, has a very positive effect. It has been shown [21] that students who offer support to other students but then fail to receive any kind of recognition for their services are much less likely to continue to be motivated and effective mentors. Those who receive recognition for their work also experience an increase in self-esteem, self-confidence and affirmation of professional competence. Furthermore, even though there are clear benefits to student mentors in terms of their learning and communication, they often see the task as a disadvantage because it takes time that could be used more productively for personal study [21].

To this end, Lincoln's student expert system is underpinned through a student feedback rating system and institutional recognition. Following a thread of support accessed by a student and given by a student expert, the student receiving support is required to mark the question as being answered and asked to provide a feedback rating for the expert based on a three factors; these being response time, level of support and quality of explanations. The average feedback score for this particular thread of support, on a scale of 1-5, is then allocated to the student expert's overall feedback score. At the end of each semester, the top 5 student experts are then identified based on their feedback scores and are rewarded accordingly. This not only gives institutional wide recognition to students for their efforts in student mentoring but also encourages mentors to provide the best support possible.

7. Conclusion

This paper has presented a novel approach to mathematics support adopted by the Lincoln School of Engineering to aid the transition of students into higher education. Through this approach it has been shown that there is a marked increase in student retention compared to national benchmark figures. Furthermore, it has shown that there is a significant increase in student success for those accessing support, demonstrated by a correlation analysis and backed up by this retention data, and an increase in student engagement measured through regular student feedback. The paper has then extended this proven approach through the use of on-line diagnostic testing as a more effective method of formative assessment and more accurate way of identifying individual support requirements. Secondly, a student expert system is reported to encourage student-to-student mentoring and harness knowledge of those gifted and talented students often overlooked by higher education institutions and to allow further consolidation and review of material for second year students. It is expected that, based on the success of the current system, this will enhance retention rates and student success and engagement further and become the basis for a much more informed and structured mathematics support system. An evaluation of the impact of the on-line diagnostic approach and student expert system will be presented in a future paper.

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