The Dyslexic Student and Mathematics in Higher Education

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Difficulties that are encountered by dyslexic undergraduates with their learning and understanding of mathematics are explored. Specific consideration is given to issues arising through mathematical content, its delivery, the procedures and processes of ‘doing’ mathematics, and its assessment. Particular difficulties, which have emerged through exploratory and explanatory multiple-case studies, and witnessed through the provision of one-to-one support to a dyslexic and dyspraxic engineering undergraduate, are detailed. Recommendations for the provision of mathematical support to dyslexic students and proposals for future research are given. Copyright © 2007 John Wiley & Sons, Ltd.

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INTRODUCTION

This paper arises from a 3-year research programme undertaken with dyslexic students, in numerate disciplines, to explore the ways in which dyslexia affected their learning and understanding of mathematics. It is well documented that in many cases dyslexia impacts on numeracy skills (Helland & Asbjørnsen, 2004; Ostad, 1998) yet difficulty with arithmetic does not always preclude success with mathematics (Perkin, Croft, & Grove, 2006). Our research has shown that there are some dyslexics who obtain excellent pre-19 qualifications in mathematics and only encounter difficulties in the subject at university level. Most universities in the UK have specific departments that provide support for students with disabilities and special needs but it is rare to find universities offering specialist help with mathematics to these students. Current legislation in the UK (the Special Educational Needs and Disabilities Act (SENDA), 2001) makes it unlawful for a university to discriminate against a disabled student. Universities must make reasonable adjustments to ensure that disabled students are not placed at a substantial disadvantage compared to

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non-disabled students. What constitutes ‘substantial disadvantage’ in the study of mathematics by a student with dyslexia is unclear. It follows that what constitutes ‘reasonable adjustment’ is similarly ill-defined. The challenges, associated with the learning of mathematics in higher education, experienced by dyslexic students, any consequent impediments to their success, and possible remedial actions are therefore worthy of exploration. It is important to understand the nature and impact of these difficulties and to explore ways in which mathematics support might be adapted or developed. In turn, this understanding has the potential to inform curriculum, resource development and staff training programmes.

The Report of the National Working party on Dyslexia (1999), edited by Singleton, states that dyslexia occurs in about 4% of the population. The incidence of dyslexia in higher education is estimated at between 1.2 and 1.5% of all students, of which 57% are known to be dyslexic on entry to university. The percentage of these students studying subjects with a mathematical content is not known. Statistics show that the percentage of the student population stating that they are dyslexic on entry to university is rising. In 1994/1995 it was 0.47%, and the latest available figures for 2004/2005 show 2.47% (The Higher Education Statistics Agency in the UK, http://www.hesa.ac.uk/holisdocs/pubinfo/stud.htm).

There is a widening participation agenda in the UK; the government’s stated objective is that 50% of 18–30 year olds will experience higher education by 2010. It is expected that institutions will see further increases in the number of dyslexic students registered on their courses as the number of students entering higher education increases and access widens. There is popular belief that many dyslexic students are gifted in a visually creative way (Geschwind, 1982; West, 1997), therefore it is not surprising that engineering departments contain a high proportion of dyslexic students. Richardson and Wydell (2003) established that in the academic year 1995/1996 the highest incidence of dyslexia was found in engineering. The findings from our research will be of particular relevance to those supporting engineering students, although we also believe it to be more generally applicable given that mathematics and statistics are key components of many other courses.

If an educational psychologist recommends that one-to-one support be provided to a student with learning difficulties then universities provide support with report writing, time management and the development of compensatory strategies as required. At Loughborough University support is tailored to individual needs and one-to-one mathematics support is provided, at all stages of undergraduate study, when it is believed that dyslexia or any other learning difficulty is impeding progress in the mathematical or statistical elements of a student’s course. Our concern is that general impediments to success, arising through dyslexia, have the potential to impact negatively on success and progression in mathematics. We recognize that such support is highly specialized and there is an insufficient number of support staff with the requisite mathematical knowledge. Current research being undertaken by the authors indicates that in most universities such support is rarely available.

It is important that these difficulties and obstacles are identified, and that appropriate palliative mechanisms are developed wherever possible.
dyslexic students their self-esteem, progression and eventual success are crucial outcomes (Riddick, Farmer & Sterling, 1997). Additionally, we believe that academic staff should provide the best possible learning environment for all students with retention, success and accessibility being primary objectives.

There are publications detailing strategies for teaching mathematics to dyslexic pupils, for example, Chinn and Ashcroft (1993), Henderson and Miles (2001) and Miles and Miles (1992), however, these are primarily written to assist children up to about 16 years of age. There has been little in-depth research into the mathematical difficulties that are experienced by dyslexic students who have succeeded in pre-19 education and are reading for degrees in numerate disciplines. Searle and Sivalingam (2004) have undertaken some preliminary work and conclude ‘The possibility of a dyslexic pupil experiencing serious difficulties with tertiary mathematics despite having excelled in school mathematics is real’. Malmer (2000) highlights the fact that the connection between mathematical difficulties and dyslexia has been insufficiently appreciated. Other emerging work is that of Trott (2003a, 2003b), which describes the mathematical support she has provided for dyslexic undergraduates and suggests ways to help facilitate their learning and understanding of mathematics.

Barriers to success, encountered by the dyslexic population, may include poor short-term memory, reading and writing problems, glare from printed pages and visual disturbances (Singleton, 1999). Students, particularly those who have encountered difficulties at school may have low self esteem (Riddick, Sterling, Farmer, & Morgan, 1999). Dyslexic students often need to see the whole picture (Stein, 2001). They have many different learning styles (Mortimore, 2003) that may give rise to difficulties with material and delivery which have been developed for non-dyslexic students. As dyslexic students progress through the educational system, any difficulties they encounter may increase due to greater demands being placed upon them in areas such as note taking (Miles & Miles, 1999). With the start of higher education comes a distinct change in learning style; the pace of learning quickens and the amount of support and supervision provided diminishes (Lowe & Cooke, 2003). At this level we expect students to be autonomous and independent learners and to have developed the skills required to be so. It is also pertinent to note that any difficulties that are encountered in mathematics will be compounded if students have missed lectures. Henderson and Miles (2001) draw attention to organizational weaknesses that may result in dyslexic pupils being unable to grasp the concept of timetables. In a study undertaken with students to investigate dyslexia and everyday memory, Smith-Spark, Fawcett, Nicolson and Fisk (2004) found that dyslexic students have more everyday cognitive lapses than their non-dyslexic peers, which do not just affect written work but ‘pervade everyday life’.

The research described herein investigates the nature of learning mathematics in higher education and explores how the progress of dyslexic students might be impeded either by the nature of the mathematics itself or by the systems used to deliver and assess it. This is done through the lens of students who achieved the necessary qualifications to enter university to read for degrees in engineering and did not have low self-esteem. The
mathematical difficulties that we describe arise from three separate studies, which we will give details of later, undertaken over a period of 3 years. These are:

- Exploratory multiple-case studies (6 dyslexic students).
- One-to-one mathematics support (3 dyslexic students).
- Explanatory multiple-case studies (12 dyslexic and 12 non-dyslexic students).

It was through the provision of one-to-one support that we recognized problems were arising not just from particular mathematical topics. Difficulty was also found to occur with the way material was delivered, and through methods of assessment. From these witnessed difficulties and our experience of teaching mathematics we developed a conceptual framework of four components to cover the mathematical pathway to learning. These components, shown in Figure 1, are: content, delivery, procedures and processes, and assessment.

Having defined the four components that we believe have the potential to cause difficulty we then explored links between these components and dyslexia-related difficulties. Of course, pathway components are inter-related and boundaries blur, for example a student having problems with forming a logical argument in a lengthy problem will not only have problems with ‘procedures and processes’ but also ‘assessment’. Nevertheless, this taxonomy has proved useful in attempting to map out where the problems experienced actually lie and whether they are tractable. Our results indicate that dyslexic students do experience difficulties with their study of mathematics and these difficulties can be mapped to our four components. Furthermore, from our provision of one-to-one support we have determined that it is possible to mitigate against these difficulties. Additionally, we have found that there are distinct differences in approach to study and revision between the dyslexic and the non-dyslexic students.

We describe our methods of research before going on to explain why and where we might anticipate dyslexic students may have problems. We give an overview of each of the students that we refer to in this paper. We have selected these students as collectively they cover all the difficulties that we have determined. For reasons of confidentiality pseudonyms are used. We then continue by giving examples of the difficulties that were encountered linking these to our four components. This paper concludes with a summary of our solutions and recommendations for support, which, if adopted, will enhance the mathematical experience of dyslexic undergraduates. Avenues for further work are also suggested.

![Figure 1. Conceptual framework of the mathematical pathway to learning.](image-url)
RESEARCH METHODS

Several well-known authors in the field of case study research, which include, Anderson (1998), Bassey (1999), Merriam (1988) and Yin (2003) express the view that case study is an appropriate method for educational research. It is also suitable when trying to ascribe causal relationships, rather than just writing a descriptive scenario or describing a situation by detailing illustrative results (Yin, 1993). We have undertaken multiple-case studies, which have enabled in-depth investigation with evidence collected from interviews, documents and observation.

The students were recruited from two sources. A member of the English Language Study Unit (ELSU) passed on details of our research to dyslexic engineering students who were attending support sessions. The authors, in their timetabled mathematics tutorials, explained the research to three cohorts of students undertaking civil engineering, aeronautical engineering and electrical engineering and asked for volunteers. All students signed consent forms.

In all the studies we interviewed each student. The interviews were semi-structured, with a mixture of open and closed questions. The first two students did not wish their interviews to be tape-recorded; to ensure consistency we have taken notes during all the interviews. We also interviewed support staff who knew the dyslexic students in order to determine the difficulties they had observed. When permission was granted, we obtained copies of reports from educational psychologists who determined that the students were dyslexic. Additionally, we used observation with the students who received one-to-one support.

The six exploratory case studies were undertaken in year one of the research (2003/2004) to ascertain whether there was any evidence to suggest that dyslexic students in higher education are impeded in their learning and understanding of mathematics as a direct result of their dyslexia. Six dyslexic students participated in this study. Analysis revealed evidence to suggest that dyslexic students are indeed disadvantaged in this way (Perkin, 2004).

For the 3 years of this research one-to-one mathematics support was provided to three dyslexic students, one student for 2 years, one student for 1 year and one student for one semester. These students had all been awarded one-to-one tutorial support and as the support they needed was with their mathematics modules a member of the ELSU referred them to us. The mathematical support was given to the students individually on a weekly basis. Each support session lasted for 1 h. The provision of this support enabled problems that were encountered by the students to be both recorded and analysed. It is these witnessed difficulties and the mechanisms that were put in place to alleviate them that informed the body of this paper.

It was from the provision of the one-to-one mathematics support that some of the questions for the explanatory case studies were developed. These studies were undertaken with 12 dyslexic engineering students and a control group of 12 non-dyslexic engineering students during the academic years 2004/2005 and 2005/2006. The aim of these studies was to determine if there were any particular areas of mathematics that caused problems, whether there were any difficulties encountered with the way mathematical material was delivered and if current assessment procedures might be considered to discriminate. The control group
enabled us to investigate differences between the dyslexic and non-dyslexic students in their approach to study and revision.

The preferred strategy for case study analysis is that of relying on theoretical propositions and there are several specific analytic techniques that may be used. However, that of cross-case synthesis is specifically linked to multiple-case studies (Yin, 2003). We have used cross-case synthesis to map our data to the predetermined categories, namely our components. All the data fitted into our conceptual framework.

MATHEMATICS IN HIGHER EDUCATION

The different areas of mathematics encountered in higher education are wide ranging and it is not only students following a mathematics, science or engineering degree that are exposed to this subject. Mathematical/statistical elements occur in many courses such as life sciences, physical sciences, economics and business. It is reasonable, therefore, to conclude that many dyslexic students will encounter these subjects. Postgraduate students who may have ‘escaped’ mathematics during their undergraduate studies are frequently called upon to use statistical distributions for the analysis of their data. Additionally, undergraduates intending to enter the teaching profession will need to demonstrate mathematical competence through mandatory numeracy tests. It is evident that the issues discussed herein have the potential to impact upon a far greater number of students than might at first be realized.

We believe that within each of our components lurks the potential for impediment that we wish to explore further. From our own knowledge and understanding of mathematics in higher education we give an overview of what each component contains, and where we believe that difficulties might be experienced.

Content

Specialist terminology, symbolism and diagrammatic representations lie at the core of mathematics content and we detail these separately. Each of these has developed over hundreds of years, to communicate mathematical ideas amongst professional mathematicians. Such representations are ubiquitous and as such, if they do cause problems, there is no real prospect of changing practice.

Terminology

Mathematics involves frequent use and precise understanding of terminology or language that is often specific to an individual mathematical topic. Some words that are encountered in everyday language have different meanings in a mathematical context; for example, words such as product (referring to multiplication), acute (referring to an angle of less than $90^\circ$) and vulgar (referring to a ‘top-heavy’ fraction i.e. $11/7$), will have been encountered at General Certificate of Secondary Education (GCSE) Level, undertaken by almost all pupils, generally at 16 years of age, in England and Wales. In mathematics at General Certificate of Education Advanced Level (GCE A Level), which may be
taken at 18 years of age by pupils in England and Wales, some additional words will be encountered. For example the word ‘differentiate’, rather than meaning ‘distinguish’, is used in relation to the slope of a curve. However, many more are encountered in higher education. The word ‘complex’, rather than meaning ‘complicated’, has a specific meaning in the context of an equation that does not possess any real roots. Similar-sounding or similarly spelt words are known to present difficulties to the dyslexic population (Henderson, 1998; Miles & Miles, 1992). For example, students in first level courses in higher education will meet the words integer and integral, which have quite different meanings and different symbols to represent them. There is also the introduction of abbreviations and foreign words that will not necessarily have been encountered previously. To progress through higher education it is not only necessary for the student to read extensively but also to interpret correctly, and to appreciate the significance of such words.

**Symbolism**

The ability to understand and apply notation is a fundamental skill at this level. The cross, \( x \), used to represent multiplication is often replaced by a dot; for example \( 2 \times 5 \) could be represented as 2.5, and to add to the confusion, 2.5 could also be a decimal representation of the fractional value of \( 5/2 \). In higher education the introduction of notation, beyond that of the ‘plus’, ‘minus’, ‘multiplication’ and ‘division’ signs is commonplace and essential. The placing of one quantity in relation to another can also radically alter the meaning of an expression. Frequent use is made of superscripts and subscripts and many expressions will contain both as in \( x^2 \). The underlining of, or the addition of an over bar to a symbol will also change its meaning and students will be required to work with both representations. The use of prime and multiple primes as in \( x', x'' \), is also commonplace. Confusion may also arise from notation that is not at all uniform since different texts and different academic staff may use disparate notation for particular operations, and perhaps even worse, use the same notation to depict different operations or quantities. For example, the symbols \( i, j \) are used for quantities known as unit vectors, and also, often in the same context, for the quite different quantities known as imaginary units. At this level there are specific symbols being linked to certain words and students need to be familiar with the word, the symbol and understand the operation, which this mandates them to do. Students will also encounter frequent use of letters to replace objects and widespread use of Greek, and other, characters. In addition to the lack of uniformity of notation, there are also some mathematical procedures that can be represented in several ways. One such example is that of vectors, which are quantities that possess both magnitude and direction. A comma may be used to separate the different directional elements of a vector. For example, a move of three units horizontally followed by a move of two units vertically could be represented as \( (3, 2) \). However, this manoeuvre could be written in the alternative form \( \begin{pmatrix} 3 \\ 2 \end{pmatrix} \), known as a column vector. During calculations with vectors it is often necessary to combine two or more of them. When two vectors are ‘multiplied’ together, this may be referred to as either the ‘dot product’ or the ‘scalar product’, and either a comma or a dot (full stop) may depict the operation.
Information is often presented in arrays of rows and columns known as matrices, for example:

\[
\begin{bmatrix}
3 & 2 & 1 \\
5 & 2 & 0 \\
6 & 9 & 8
\end{bmatrix}
\]

matrix \( A \)

In practical applications, frequently encountered in engineering, there could be many more rows and columns of numbers. Another example is that of differentiation, a process that can be used to find the gradient of a given curve (described mathematically as \( y = f(x) \)) at a particular point. The derivative represents the rate of change in the \( y \)-direction compared to the rate of change in the \( x \)-direction and can be represented in any of the following ways, and often more than one of these equivalent representations will be used within the same calculation.

\[
\frac{dy}{dx}, \frac{df}{dx}, y', f' \text{ or } f_x
\]

Other difficulties may occur with symbols that look very similar such as, \( \partial \), \( \delta \), \( \delta \), \( d \)

Whilst these have very different meanings mathematically, unfortunately they may also all be encountered within a single calculation and pose particular difficulty for students who experience visual disturbance whilst reading.

Diagrammatic representation including graphs and charts

As mathematics practitioners we were not aware of any difficulties being encountered with diagrammatic representation unless it was of a particularly technical nature such as encountered in systems engineering. However, as we will detail, two of our dyslexic students did experience difficulties in this area.

Delivery

Mathematicians are great advocates of the traditional ‘chalk and board’ lecture. It is the nature of doing mathematics ‘live’, with the ability to return to and amend or correct earlier work, which lends itself to this form of delivery. This does not provide a good environment for the use of recording devices within lectures. For example, a lecturer might write out an equation without actually reading aloud what has been written. Various elements may be referred to or simply pointed out. After giving a worked solution to the problem, the lecturer may then change part of the original equation and explain why the method just demonstrated would not work for this new problem. What then remains on the blackboard is no longer a correct solution and could well pose a problem to those students who had not finished copying the original. Students are also expected to make use of printed handouts, textbooks and computer-based learning materials. They may be required to work in groups and so experience ‘delivery’ of the mathematics they need from other students.

The British Dyslexia Association (http://bdadyslexia.org.uk/extra352.html) recommend the use of sans serif font and this is now the norm for text in
examination papers and printed handouts at Loughborough University. Mathematical symbols and Greek characters are, however, often presented in a variety of different fonts with letters that are used in equations and formulae frequently presented in italics, i.e. \( l \) and \( x \), to avoid confusion with the number 1 and the symbol for multiplication.

**Procedures and Processes**

A topic frequently encountered in undergraduate mathematics is the solution of equations. Solving two equations containing two unknown quantities will have been encountered at school, however, when the subject is encountered in higher education the number of equations and the number of unknown quantities is frequently far greater. Additionally, it is often necessary for the student to first extract the required information from a lengthy descriptive text. Whilst this is a procedure that many non-dyslexic students find difficult, the problem is far worse for students who encounter difficulties with predominantly text-based material.

It may also be necessary to present the information in a matrix prior to commencing any mathematical operations. When more than one of these matrices is involved, operations become more complex. For instance, to multiply two of these matrices together involves the student multiplying every element in each successive row of the first matrix by every element in each successive column of the second matrix. Not only does this operation require ready recall of ‘times tables’, a feat that many of the dyslexic population have difficulty with (Miles, 1992) but the problem is also compounded for those students who experience visual disturbance. The process requires holding the products of several numbers in short-term memory and there is an expectation that students will be able to do this.

Many methods depend upon the execution of several distinct operations, the results of which are then combined to form the required solution. These multi-stage operations fall into two categories; one requires an ordered sequence of operations to be calculated and the other depends upon the equation that is given and requires a decision to be made as to which operations are needed and these may be performed in any order. We have observed that for students who have working memory limitations, these multi-stage operations are particularly fraught with difficulty as students may forget to perform one or more of the steps or lose track of which stage they are computing.

**Assessment**

Many different methods of assessment are used throughout higher education. Students will have encountered a variety of methods such as multiple choice examinations, class tests, coursework and written examinations during their school years. However, in higher education there are also additional examination procedures that might be encountered, these include group project work, dissertations often with a viva voce component, presentations and computer-assisted assessment (CAA).
THE STUDENTS

The students we detail in this paper (see Table 1) had all been diagnosed as dyslexic after their undergraduate studies had commenced and therefore, had not previously received any form of dyslexia-related support. The difficulties they encountered are representative of those encountered by all the students participating in our research.

Exploratory Studies

Tom obtained four GCE A Levels; Physics Grade A, General Studies Grade A, Mathematics Grade B and Chemistry Grade E. It was during his A Level study that Tom first noticed a disparity between his knowledge and understanding compared to his examination results. During the second year of his Materials Engineering degree he missed 1 month of lectures due to illness. He subsequently found it impossible to absorb the material he had missed by reading the lecture notes and realized that if he had attended the lectures and listened to the lecturer he would have remembered much of the content. It was the suggestion from a dyslexic friend that Tom might be dyslexic that prompted him to undergo screening. Tom was subsequently diagnosed as dyslexic. He has now graduated with a second class honours, lower division degree.

Ryan obtained Grade A passes at GCE A Level in Chemistry, Mathematics and Physics. In General Studies he obtained Grade E and explained ‘I realized that an information gathering format was not right for me’. In mathematics, Ryan encountered difficulties with questions that were predominantly text based or require a descriptive answer. It was in the third year of his MEng degree in Systems Engineering that Ryan began to feel frustrated. He was undertaking a group project and was unable to explain and communicate his ideas to the group. After reading leaflets on dyslexia and seeing a self-help checklist he believed that he might be dyslexic. Ryan was subsequently diagnosed as dyslexic. He has now graduated with a first class honours degree.

Explanatory Studies

Stuart was 26-years-old when he entered university with Business and Technology Education Council (BTEC) qualifications. It was a combination of difficulties with note-taking, with understanding his timetable, seeing the dyslexia notices around campus and the fact that it had been suggested that
his younger brother may be dyslexic that prompted Stuart to undergo screening. He was subsequently diagnosed as dyslexic during the first year of his Air Transport Management Course. He has now graduated with a second class honours, lower division degree.

Alan obtained three GCE A Levels; Grade B in Chemistry and Mathematics and Grade C in Biology. He explained that whilst at school he often failed to obtain the grades he expected. However, it was a combination of his younger brother being diagnosed as dyslexic, difficulties with note-taking and time management, and the poor marks he received on a CAA that prompted him to undergo screening for dyslexia. He was subsequently diagnosed as dyslexic during the third year of his MEng degree in Civil Engineering. Alan has now graduated with a second class honours, upper division degree.

One-to-one Support

Whilst at school Patrick was labelled as a lazy pupil who had good potential. Patrick sat his A Levels twice, the first time at his local college where he obtained PE Grade C, Chemistry Grade D and Physics Grade E. He then enrolled on an electrician’s course and, as one of the few students with an A level background, was selected for an apprenticeship, which allowed him to attend college on a day release programme. Patrick found the work boring and repetitive and decided to apply for a place at university. He accepted a place on a foundation programme at a London university. However, he only remained at this university for 2 months; he found the area he was living in to be extremely rough and within the university fighting was occurring in lecture theatres.

He decided to return to college and retake A Levels in order to improve his grades. He subsequently obtained Chemistry Grade B, Physics Grade B and Mathematics Grade D. Patrick was 21-years-old when he entered university to read for a MEng in Civil Engineering. Shortly after commencing his undergraduate studies he obtained an abysmal result on a multi-choice CAA, which contained material he understood. After looking at literature on dyslexia and following discussion with a member of staff he underwent screening. He was subsequently diagnosed as both dyslexic and dyspraxic. Patrick successfully completed the first two years of his degree course and is now undertaking a year in industry.

DIFFICULTIES ENCOUNTERED AND SUPPORT PROVIDED

We now link the difficulties that have emerged through our research to our four components, and detail the support mechanism we developed with Patrick.

Content

Stuart encountered problems with words that have a similar spelling and to distinguish between such words he drew diagrams to create a pictorial distinction. He experienced difficulties in distinguishing between zero (0), and
the letter O, and in recalling what the letters in a formula represented. He encountered difficulties with the graphical interpretation of curves saying, ‘I needed to pencil in an extra line to establish where a particular point on a curve was located otherwise it just appeared to be floating about in thin air’. When calculating the area under a curve, he also needed a diagrammatic representation of the area in question. He needed to colour in the area he was calculating and place the $y$-axis on both sides of the graph to prevent himself losing track when moving from the left to the right hand side. Patrick encountered difficulty in distinguishing between the graphs of the sine and cosine functions. We used the mnemonic ‘sine rhymes with line’ to enable Patrick to recall that the sine curve contains a ‘line’ through the origin.

**Delivery**

Stuart found the text he encountered in mathematics difficult to read, even if the presentation was in a sans serif font. His personal preference is for Comic Sans. He uses this on his own computer, explaining that it appears slightly three-dimensional, which makes it appear to rise out of the page and he perceives this font as being more like an image than a letter. He also uses a cream background on his computer, which helps to reduce the glare that he experiences. He would like material on handouts to be double-spaced and printed on an off-white paper. Ryan reported problems with text-based material, he frequently loses his place when reading, which results in him either missing out part of the text or reading sections twice.

For lengthy mathematical procedures the delivery speed in lectures was often too quick for Patrick to follow, unless it was a topic that he had previously met. Patrick was able to take his own notes but explained that he was frequently still copying from the board after his peer group had finished, which resulted in him missing any explanation of the solution that was given by the lecturer. This problem has now been alleviated as Patrick checks his notes with a friend and switches on his tape recorder when a lecturer is discussing a particular topic or explaining how to implement a particular method as opposed to writing on the blackboard. He also reported difficulties when isolated new methods of computation were introduced, as he was unsure where they fitted into the topics he had already encountered. He needed to see the whole picture. It was explained to him that some topics were building blocks (addition, subtraction etc.) others were tools (differentiation, factorization, etc.) and particular areas of mathematics would use both building blocks and tools. A diagrammatic approach was frequently used with Patrick to help him link together associated methods and operations. A large amount of rigorous proof is not included in engineering mathematics but Patrick always wanted to know why a particular method worked and frequently requested to be shown mathematical proofs.

One particular area of difficulty in this component that was experienced by all of the dyslexic students, and was often the main reason for the students suspecting they might be dyslexic was that of taking notes in mathematics lectures where every detail needs to be copied from the blackboard not only quickly but also accurately.
Procedures and Processes

Stuart encountered problems with multi-stage operations. He explained, ‘If I tried to pick up a problem part way through, I just got lost. I needed to compute stage 1 before I moved on to stage 2. It was impossible for me to go to, say stage 6, without first having worked out all of steps 1–5’. He elaborated on this by saying ‘I had to learn each step individually and give each of these steps a label, once I had named each step I was OK so long as I worked through all the steps involved in the order which I had labelled them’. Patrick also encountered the same difficulties; if a question contained enough information to enable the calculation to be commenced at stage 3 he was unable to do so; he had to start the calculation from the beginning. This resulted in him not only spending extra time on the question but he also ran the risk of making computational errors. A detailed model answer was provided for him with each stage clearly numbered. The original model answer was then updated and colour coded to show the particular stages in the operation where he might be able to begin a calculation depending upon the precise information given. Then in matching colours we added examples of the way this information would be presented.

Patrick fully understood the procedures involved for solving systems of equations using row operations and did not feel that he needed any assistance with this topic yet when his solutions were scrutinized most of them were found to be incorrect. The visual disturbance that he experiences results in him incorrectly lining up rows and columns of numbers in these calculations. It is possible to design graph/squared paper to a student’s own specification, i.e. both the colour of the lines and the colour of the paper may be chosen (http://incompe tech.com/beta/plainGraphPaper/). A remarkable improvement in accuracy was observed with Patrick when squared paper was used for such operations. The simple idea of using two matchsticks or ‘lolly-pop sticks’ to cover up the row and column, which were not being used in matrix operations also proved greatly beneficial to Patrick and significantly reduced his errors. He also encountered problems moving from a 2-d to a 3-d conceptualization in vector work. The construction of a simple physical 3-d model enabled Patrick to visualize the situation.

The greatest mathematical difficulty Patrick encountered during his second year was with the topic of Fourier series. This is a procedure that enables a complicated expression to be approximated by a succession of simpler terms. His understanding of what a Fourier series is, what its graphical representation would be if a sufficient number of terms were to be taken, and his ability to distinguish between the different approaches that could be used depending upon the particular question posed were excellent. Patrick did not have any difficulties with the mathematical operations that were involved and he was able to explain these orally. To obtain a Fourier series is a multi-stage operation and the calculations, which use several different formulae, may be performed in any order. We successfully used mnemonics to help Patrick recall these formulae, which are all very similar. The results are then inserted into a final formula, which, interestingly, Patrick could recall although to do so was not necessary as it is available in examination formulae booklets. After several sessions Patrick announced, ‘I’ve got Fourier series pretty well sewn-up now’. This statement was
somewhat alarming, as Patrick had, at this time, failed to complete all the required stages without being prompted.

The problems experienced by Patrick were related to his working memory limitations and resulted in him not completing all the necessary steps. If at the end of a question he remembered to write out the Fourier series then he discovered his omissions and was able to perform the missing calculations and hence complete the question. However, what recurrently happened was that he failed to complete the last stage of the operation—writing out the actual Fourier series, i.e. the answer. If he had also failed to compute all the necessary calculations he could only obtain approximately half the available marks. Eventually this was overcome by repeatedly telling him ‘the most important thing is to write out the Fourier series at the end of the question’. Patrick actually started to talk out this sentence aloud at the end of each question and thereby discovered any omissions.

At the time of supporting Patrick it was believed that the rapid pace at which he worked was natural to him. However, this characteristic was also observed with both students who subsequently received one-to-one support. Patrick has since been questioned on his speed of working and told us ‘I went quickly because I was frightened that I would lose track of where I was going’.

One question we asked the dyslexic and non-dyslexic students who participated in the explanatory studies was ‘are there any areas of mathematics which you understand but for which you frequently obtain incorrect answers?’ Only one of the non-dyslexic students answered yes and attributed this to ‘sloppy arithmetic’, moreover, two students explained that if you understand mathematics you obtain the correct answer. Whereas 10 of the dyslexic students answered yes to this question, the topics that were cited were the use of statistical tables, operations involving rows and columns of figures and multi-stage operations. Another question we posed was ‘do you use mind maps for mathematics?’ and this also produced a very marked difference in response between the dyslexic and non-dyslexic students. None of the non-dyslexic students used mind maps and many could not comprehend how they might be used for mathematics and asked if this was possible, whereas seven of the dyslexic students drew mind maps for themselves and made comments such as ‘they are an invaluable part of my learning process’, ‘they are essential for revision’.

Assessment

Tom had difficulty in extracting what was actually being asked and what was required in examination questions and is convinced that if he were to be given a viva voce examination he would obtain better marks. Alan and Patrick had difficulty with multiple-choice CAA. Ryan encountered difficulty with an assessed group project when he discovered that he was unable to explain and communicate his ideas to the other members of his group; they thought he was being stupid and laughed at his written work. Ryan noticed that coursework was taking him far longer than his peers and Stuart described his final year dissertation as ‘an overwhelming task’.
Patrick often ‘rushed headlong’ into answering questions without reading them correctly. This has sometimes resulted in him answering what he thinks is being asked rather than doing what is actually required or even missing out part of a question. In statistics questions, containing lengthy descriptive text, Patrick often failed to identify key words such as *continuous* or *discrete*, which resulted in him incorrectly answering questions. Whilst practising examination papers, which required only a certain number of questions to be answered from those given, Patrick would only look at part a of a question. If he felt able to do this part of the question he would launch straight into answering it and subsequently he often came to grief on parts b and c. Time was spent discussing the best use of the 25% extra time allowance for examinations. It transpired that it was beneficial for Patrick to use half the extra time to read through the paper thoroughly, highlight key words and decide which questions he would answer and then use the remaining extra time for checking his work.

INVENTORY OF SOLUTIONS

We have used a variety of techniques to help with each of our four components. For difficulties with content we have used mnemonics to help students link graphs to functions. For procedures and processes we have encouraged students to draw mind maps, given diagrammatic representations, used mnemonics and colour coding to aid recall of procedures and provided detailed model answers. Colour coded concept diagrams have been used by Trott (2002) during one-to-one support sessions and have been found to assist dyslexic students with multi-stage mathematical operations. Regarding assessment we have helped our students to develop examination techniques and obtain maximum benefit from extra time allowances.

RECOMMENDATIONS

Once a student has been identified as needing mathematics support it should be put in place as quickly as possible. This support differs significantly from that which is available in tutorials or in mathematics support centres as it can address the particular ‘components’ with which the student is experiencing difficulty and develop compensatory techniques accordingly. Another beneficial aspect of one-to-one support is that the student sees the same tutor each week thus establishing a comfortable working relationship. The speed of delivery and the length of time spent studying a particular topic can be tailored to students’ individual needs.

Mind maps could be designed and made available for commonly encountered multi-stage mathematical operations and then during one-to-one support sessions students could be encouraged to produce their own.

Some of our dyslexic students use a coloured overlay (the colour used varied from student to student) to reduce glare from the text they were reading but this is not always practical as they may wish to annotate a printed handout. Producing black text on an off-white background would therefore be beneficial. The provision of squared paper in examinations halls would also help those
students who have been using this paper to assist in the lining up of rows and columns of numbers.

We believe that professional development courses, covering dyslexia and the components we have referred to should be mandatory for mathematics lecturers. These could give an overview of dyslexia and its associated difficulties with emphasis on the different learning styles that students may have. The importance of pacing delivery, different modes of delivery, diagrammatic representation and the value of providing clear, well structured and timely handouts could be emphasized. A heightened sensitivity to the needs of the dyslexic students in one’s class would result in substantial improvement to the learning experience.

CONCLUDING REMARKS AND FUTURE RESEARCH

We investigated whether general impediments to success, arising through dyslexia, had the potential to impact negatively upon success and progression in mathematics. We have shown through our research that this is indeed the case. We have linked observed mathematical difficulties to our conceptual framework. We have shown that through the provision of dedicated, specialist support, and by teaching dyslexic students alternative strategies they can overcome many hurdles and make progress. We believe that through improvements to teaching practice many more dyslexic (and non-dyslexic) students could be helped. It is evident that many dyslexic students would benefit from additional support with the mathematical elements of their courses. Leaflets detailing strategies for coping with the mathematical elements of courses would be an invaluable addition to the study skills support literature already available.

There are many avenues for future research, and as Riddick et al. (1997) write, ‘There is, as yet, little systematic published research into dyslexia in higher education’. The Dyscalculia and Dyslexia Interest Group (http://ddig.lboro.ac.uk) is making inroads here. However, it is imperative that more extensive collation of existing research and good practice be undertaken. One particular area, arising from the case studies, and also raised by Wiles (2002) is whether multiple-choice examinations, often used to test mathematics, discriminate against dyslexic students. A large-scale comparison of the performance of dyslexic students who were diagnosed at school with those who were not diagnosed until after entering higher education may determine whether compensatory strategies learnt in school are transferable to higher education. Finally, it is evident that there is a need for additional focused in-depth research in the field of dyslexia, mathematics and higher education if other students like those we have described here are to succeed and fulfil their potential.

References


Dyscalculia and Dyslexia Interest Group http://ddig.lboro.ac.uk (accessed 26/06/06).


Higher Education Statistics Agency—student tables http://www.hesa.ac.uk/holisdocs/pubinfo/stud.htm (accessed 04/12/06).

Incompetech.com—free online graph paper http://incompetech.com/beta/plainGraphPaper/ (accessed 26/06/06).


