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The Importance of a Mathematics Diagnostic Test for Incoming Pharmacy Undergraduates

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The expansion of higher education in the UK in the 1980s and the subsequent increase in student numbers has created greater variation in cohorts of students entering university. Entry requirements are more relaxed and students with lower pre-university (A-level) qualifications or alternative qualifications (BTEC, GNVQ) are routinely accepted onto MPharm degree programmes within the UK. Mathematics is a key component in the pharmacy degree programme and an understanding of basic mathematics is essential.

This wide variation in mathematical ability coupled with increasing class sizes has led to various strategies being introduced to ensure that all students attain the required level of mathematical ability to complete the degree programme. This study investigates the use of a diagnostic test to improve both the teaching and learning experience.

The paper describes an investigation into what may be learnt about students' background knowledge and skills from initial assessment and information about their prior qualifications, and how this information may be used to devise effective teaching and learning strategies.

Keywords: Mathematics; Pharmacy; Undergraduate; Diagnostic test; Pre-university

INTRODUCTION

A common complaint from university lecturers relates to the mathematical ability of undergraduate students. There is debate about the perceived decline in standards of mathematical knowledge and skills of students enrolling at university each academic year. However, of the 17 MPharm degree courses listed on the UCAS web pages in 2003 (http://www.ucas.ac.uk/, Accessed February 2004), only two institutions stated that A-level mathematics was preferred for entry. All institutions stated that Chemistry A-Level was essential and the majority stated that Biology was preferred as an additional A-Level, with Maths being acceptable as a third choice. All programmes required Mathematics GCSE at grade C or above and no comments were made about AS Levels (see Glossary of Terms). Thus, students that arrive as undergraduates have demonstrated the required mathematical ability to begin the degree programme. The issue here lies in the mismatch between university lecturers' expectations of student knowledge and students' actual mathematical ability. A number of contributing factors may be identified to account for this mismatch:

- University staff are often not up to date on the latest developments in pre-university education,
- Mathematics is taught by non-specialist lecturers,
- University lecturers were not typical students even at the time when they were undergraduates, and, in many cases this was 10, 20, 30 or even 40 years ago.

A recurring problem faced by a lecturer teaching first year mathematics to undergraduate students is in deciding where to start and what background knowledge and skills can be assumed. This is a common issue that has been highlighted previously: "If I had to reduce all of educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (Ausubel, 1968). Increased access to university and the diversity within syllabuses and curricula at the school level mean that there is inhomogeneity within each incoming student cohort.

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In addition, it is not easy to predict students' knowledge and skills from their entry grades. There are currently four examination boards in England and Wales that offer national A-Level qualifications. Each of these boards may offer more than one A-Level specification; for example mathematics with statistics or with mechanics. There is only 40% common material between the different A-Levels currently offered, thus the common content each student has studied is limited (Bishop and Hibberd, 2001). In addition to this variability among A-Levels alone, students arrive with a whole array of prior qualifications; the lowest common denominator is GSCE grade C or an equivalent.

A decline in the standards of mathematics qualifications has been well documented. Each year, as A-Level results are published, there are media reports that suggest these exams are becoming easier (Harrison, 2003). Although these claims are usually refuted, separate studies have demonstrated a decline in the competency of students over time from 1991 to 2000 (Cox, 2000). It is also interesting to note that in 1965, when grades were first awarded for A-Levels, the percentage of students that obtained the highest grade was capped at 10%; in 1982 this cap was removed and in 2003, 38.9% of all students who took A-Level mathematics were awarded a grade A (Harrison, 2003). However, concerns have been expressed about the reduction in students that take mathematics as an A-Level subject (Mustoe, 2002). In addition the numbers of undergraduates within each first year has almost doubled over the past 10 years at Aston University and this is comparable to other schools of pharmacy.

The change in standards of students entering higher education has led to new strategies being employed in teaching these large groups of mixed ability. Difficulties that are faced by a teacher with a large group that has variable mathematical ability include:

- Identification of those students that are struggling,
- Finding an appropriate level at which to pitch a lecture,
- Provision of useful feedback to all students,
- A mismatch between the university teachers' expectations and the students' actual capabilities.

There is insufficient time to re-teach the entire A-Level syllabus at university, thus it is essential to focus on specific areas. Strategies include additional modules or courses to bridge the gap from pre-university to university requirements, computer-based learning packages to supplement the curriculum or streaming students into groups dictated by their ability.

Useful tools to address some of these problems highlighted above include diagnostic tests. Diagnostic testing in mathematics has been used increasingly by Departments of Engineering, Physics and Mathematics (Cox, 2000). A well designed, graded diagnostic test is a valuable tool in tackling most of these issues. The design of such a test is critical if a realistic picture of the knowledge base of students is to be gained. The learning outcomes of a particular lecture series should be borne in mind when designing the test, and these should be tested with short, focused questions. It has been suggested that intense tests, given at short notice with no revision allowed, provides the best indication of what information students have at their fingertips and thus best represent the skills of the students (Cox, 2000).

The purpose of the test should be clearly defined in order that the students gain a true reflection of their ability. The results from the test should be used by the teacher to best design a course that will ensure all students achieve the learning outcomes. The students should use their personal result to evaluate their own capabilities, and to gain an insight into the level of knowledge that is expected of them within each course. Immediate feedback and anonymity reduce the feeling of failure of each student, as they may be able to visualise their weaknesses and concentrate on areas where they need to improve. Rapid analysis by the teacher is often essential due to timetabling issues whereby the next session may be scheduled within the same week. Ideally a series of lectures may be devised to specifically tackle aspects of the course, based on the results of the diagnostic test. Students can choose to attend sessions on the basis of their own score within the diagnostic test; this should reduce student numbers within teaching sessions and enable easier identification of those students that are struggling. Additional material should also be made available for students that is relevant and may easily be matched to their weaknesses.

A significant advantage of diagnostic assessment includes rapid evaluation of knowledge base for both students and lecturers. Although students' entry grades are available, differences in examination boards and dates that the qualifications were obtained mean they are often not a true representation of the mathematical ability of a student (White, 2002). In many cases, the student may not realise their mathematical ability, or more likely they are not aware of the mathematical ability required for a Master's of Pharmacy Degree programme, thus the diagnostic test is useful to them. One disadvantage of such tests includes poor performance in such a test potentially lowering students' expectations of themselves. Furthermore, diagnostic tests are reliant upon students performing on the day they are administered and they are often administered without warning.

A diagnostic test provides an immediate mathematical ability guide for both the student and the academic. The academic gains an insight into the ability of the cohort, and can structure teaching sessions appropriately. There are several factors that may be considered, including streaming students and providing additional resources that are accessible to students. The standard approach is to split the cohort into groups based on their ability where their needs will best be met. However, there are a range of teaching and learning strategies that may be better employed in reacting to these large groups of mixed ability. Focused lectures, intensive tutorials, example classes, resource-based, self-paced learning, group work, peer and self-assessment are all valuable strategies that can be employed in teaching mathematics to undergraduates. However, resources and options are limited, thus effective use of the information gathered in the diagnostic test is essential. The results from the diagnostic test will demonstrate the strengths and weaknesses of the group overall and those areas that are weak may be taught from scratch to the entire group. For those learning outcomes that demonstrated wide discrepancies, it is unlikely that they can be taught effectively to the entire group in a conventional way. However, there is often no need to physically separate the group; it may be sufficient to provide appropriate resource-based and self-paced learning materials.

A possible teaching and learning strategy based on the results of the diagnostic test may be as follows:

- Consolidate the basic skills: this may be done as self-paced learning with appropriate resources,
- Teach learning outcomes that demonstrated a low score in the diagnostic test; a mix of traditional lectures, workshops and focused tutorials may be used,
- Channel additional teaching effort into those areas where wide variability was noted: additional lectures or tutorials and additional self-paced learning resources may be provided.

The above strategy allows an effective use of teaching time, provided there are sufficient resources for the student group. The teaching strategy outlined above may be designed in advance based on the knowledge of previous incoming student groups, then refined within a short time to incorporate additional needs of each year group on the basis of the diagnostic test.

In addition, material relating to these subjects and practise examples may be distributed either as paper copies or within virtual learning environments. Virtual learning environments offer anonymity to students who may benefit from using practise questions, and also offer immediate feedback and can be used on an "as required" basis. Once set up, they can be used in place of face-to-face sessions.

A report by The Engineering Council (2000) on evaluating the mathematics problem recommended:

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

AIMS OF THIS STUDY

Comparable diagnostic tests have been used with first year pharmacy students at Aston University for the past few years. The results from several cohorts have been analysed and the likely strengths and weaknesses of an incoming group have been discovered. A teaching strategy has been developed that may be used as a starting point for each new group. In designing an effective diagnostic test it is important to itemise and evaluate a full range of key knowledge and skills that are required for the course. In 2003, every student was tested against key requisites of mathematical knowledge and skills that are essential for the first year degree programme using a paper-based multiple choice diagnostic test. It was anticipated that the students would have seen most of these operations before, hence the aim was to test not only their prior learning but also the information that each student had at their fingertips. Analysis of such a test allowed an appropriate teaching and learning strategy to be devised after the diagnostic test had been delivered. These tests were performed during the first week of term prior to a short lecture course designed to introduce students to basic mathematics. At the end of the course a second questionnaire of similar design was administered allowing the progress of the students to be monitored over time. Additional material, in the form of short tests on specific areas, was provided for all students to use within a virtual learning environment.

METHOD

Application forms from the first year undergraduate cohort were used to discover the background knowledge of the student group. These forms were compared to the forms from students' entry in 1993.

A series of six lectures that cover basic mathematics was timetabled for all first year students within the first two weeks of term one. The aim of this lecture series was to provide students with an understanding of basic mathematical principles important in the collection, manipulation and interpretation of relevant experimental data for drug formulation and delivery. A list of core knowledge and skills was devised based on the first year syllabus. The question paper was divided into topics covered within the lecture series: numbers and operations; fractions, ratios and percentages; power functions; logarithms; rearranging equations. The learning outcomes were tested using short, highly focused multiple-choice questions. Multiple-choice questions were used to allow rapid marking and analysis of the data so that an effective course could be designed within the allocated time-scale. Table I lists some of the skills that were required, with example questions used to assess those skills.

This multiple-choice test was administered during week one of term one with no prior warning; students had 50 min to complete 22 questions. Each student was required to fill in an answer grid that was submitted anonymously for marking. They were permitted to take away the question paper and were encouraged to mark their answers on this paper. The correct answers were available immediately after the lecture within a virtual learning environment (WebCT, http://lhs-236.aston.ac.uk:8900/webct/public/home.pl, available locally on the Aston intranet) so that students could check their own answers and identify their strengths and weaknesses. The students were provided with information about the format and content of the lecture series as well as additional resources available to them. Based on their result in the test, they could select those lectures they thought necessary and also which resources they would use. The resources available to the students included recommended reading in selected textbooks, self-paced tutorials within the virtual learning environment and short tests. An example of the range of material is provided in Fig. 1.

Although additional material was available to students in the form of textbooks and web-based packages there was no means of tracking the use of all these facilities. However, six short quizzes were written and made available for self-assessment via WebCT. These quizzes were written to tackle those areas with which previous students had demonstrated the most difficulty: unit conversions, simple operations, fractions, moles and molar concentrations, powers and logarithms and concentrations. Access to WebCT required students to input their user name thus the "hit rate" from the student group was monitored. The students were aware that these quizzes were available for self-paced learning and the scores gained were not assessed formally.

The aim of the lecture series was to ensure that all students were capable of performing basic mathematical operations regardless of their previous mathematical education. This was assessed, after the lecture series, by administering a second multiple-choice assessment that was similar in design and structure to the diagnostic test.

RESULTS AND DISCUSSION

Analysis of the highest mathematical qualification on entry showed that in the current study first year (2003–4) of pharmacy undergraduates at Aston University, 31.9% of students have A-level; 17.4% of students have AS Level, and 36.1% of students have a GCSE at grade C or higher. The remaining 14.6% of students had qualifications that were non-traditional or from outside the English system that were equivalent to a GCSE grade C or higher. Students who enrolled during 1993 showed the following results: 59.8% had A-level, 19.5% had GCSE and 20.7% had non-traditional or foreign qualifications that were equivalent to GCSE grade C or higher. This result highlights that the percentage of students arriving with an A-level in Maths has halved. This reduction in students with the highest entry qualification, coupled with the evidence of a decline in the standard of the A-level examination provides evidence to justify claims that there is a decline in the mathematical ability of undergraduate students.

TABLE I Questions were designed to test students' knowledge of key areas

Sample question	Answer	Designed to test	% of correct answers	
			Initial test	Final test
$6 + 3 \times 5 - 6 \div 2 =$	18	Priority of operations	55.3	92.5
$10^8 \div 10^4 =$	10^4	Manipulation of powers	69.3	86.0
$\ln a + x \ln b =$	$\ln ab^x$	Manipulation of logs	48.8	80.3
200,000 μg =	0.2 g	Converting units	49.5	66.7
$y = ax^n$;	$x = (y \div a)^{1/n}$	Rearranging equations	67.7	72.5
$3x^2 + 2x = 8$;	$(3x - 4)(x + 2) = 0$	Factorisation	64.7	79.0
1000 ml of 0.5 M HCl;	18.25 g HCl	Concentrations	40.9	78.3

The table above shows the results of the tests taken before and after the lecture series ($n = 142$ and $n = 157$, respectively).

Questions 9,10 and 11 tested your ability to convert units. Lecture 3 will focus on this topic. For additional material;

- Short test on WebCT - labelled "Converting Units"
- Chapter 2, "Systems of units" in Introduction to Pharmaceutical Calculations by J A Rees, I Smith and B Smith.
- Chapter 1, "Comparing metric measurements" in, Nursing Calculations by J D Gatford and N Phillips.
- PC CAL Packages – Basic Calculations in Pharmacy
    - Conversion between concentrations
    - SI units and terminology

FIGURE 1 Example of the range of material provided to students after diagnostic test.

The results from the diagnostic test highlighted the variation in the knowledge base of the student cohort. Table I shows example questions that were used in the diagnostic test and the percentage of correct answers given by students in the initial diagnostic test and the final test.

As expected, the students' performance improved following the lecture series, suggesting that this short course achieved its objectives in teaching students about basic mathematics. Table II shows how the variation in results compared in the tests given prior to, and immediately after, the lecture series.

The results show that the mean grade improved, as expected, after the lecture course. It is interesting to note the values for the median, mode and range, as these demonstrate that the variability amongst the students is much lower in the final test, suggesting that initial problems with a large and inhomogeneous cohort have been somewhat reduced. These results are shown diagrammatically in Fig. 2.

Figure 2 shows that almost 60% of the year group scored more than 80% in the final test compared to 12% achieving this score in the initial test. However, there are still concerns over those students that achieved less than 50% in the final test. The anonymous nature of this test meant that weaker students are not identified, thus it was important to encourage these students to seek additional help in order to achieve the required standard (set as the mean score in such a test).

Additional material, in the form of short tests on specific areas, was provided for all students to use within a virtual learning environment (VLE).

TABLE II A comparison of the statistical information collected from the tests used to measure mathematical ability

	Initial result ($n = 142$)	Final result ($n = 157$)
Mean grade (% ± s.d.)	61.2 ± 18.8	78.1 ± 16.5
Median (%)	66.7	81.8
Mode (%)	75	86.4
Range (%)	0–100	27.3–100

Student access to the VLE was monitored and the results showed that 70% of the student population accessed the area relating to this mathematics course. Analysis revealed that the tests were accessed by only 37% of the students within the course. Of these students, further analysis demonstrated that of these users almost half (48%) had at least an AS level in maths. This result suggests that the students for whom these tests were designed, those with lower mathematical background knowledge, were not using these facilities. In addition, as highlighted in Table III some quizzes were used to a greater extent than others; the reasoning for this needs to be explored more fully.

Approximate head counts were noted within the timetabled lectures and approximately 70% of the full cohort was attending each lecture. At this stage in the term, the average lecture attendance is 90–95% thus a small fraction of students were choosing to not attend this course, despite a third of the students having A-level maths.

CONCLUSION

Diagnostic testing alone is of limited value; it needs to be accompanied by a programme of support for all students within any given cohort. This study demonstrated that a short lecture course that focused on the weaknesses of the cohort present was effective in improving the mathematical competence of the students. The diagnostic test revealed weaknesses in the cohort to the academic tutors and also provided students with a clear picture of the mathematical skills required for their programme of study. Development of a handbook of resources that are relevant to the course is essential; it provides students with focused exercises to perform and clear targets of the mathematical competence expected of them. In turn, this reduces the face-to-face contact time. Further studies need to be performed into the usage of the additional resources

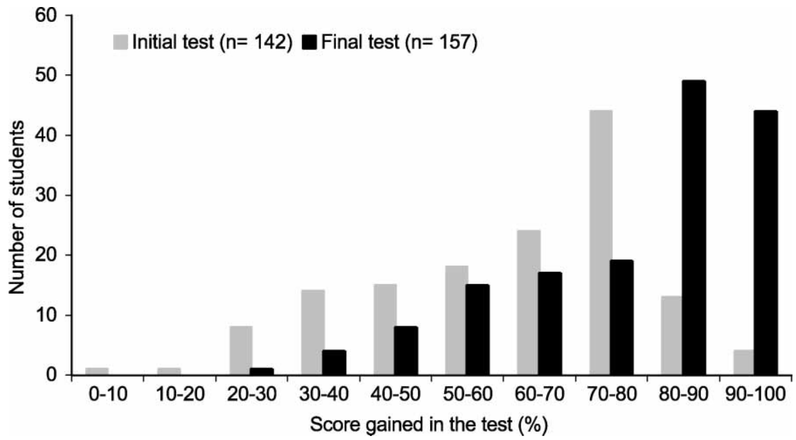

FIGURE 2 Student scores from the initial and final tests.

TABLE III The number of hits for each quiz indicates how many students participated in the quiz (total student number was 158)

Quiz title	No. of hits
Unit conversions	51
Simple operations	55
Fractions	53
Moles and molar concentrations	15
Powers and logarithms	19
Concentrations	4

provided to ensure that students are aware of this material and are using it effectively. This strategy of teaching mathematics to undergraduates is simple to administer and is an effective use of staff time. A multiple-choice diagnostic test was preferred as it is simple to mark, thus analysis is rapid. There has been much interest surrounding web-based diagnostic testing [e.g. Mathletics (Greenhow, 1998)], however, paper-based testing provide students with a hard copy of their initial performance that may be reviewed at a later date.

A diagnostic test followed by an appropriate teaching and learning strategy can help to combat the inherent difficulties that are associated with teaching first-year mathematics within the MPharm degree programme.

GLOSSARY OF TERMS

A-Level Advanced Level (taken at 18)
AS Level Equivalent to half an A-level (taken between 16 and 18)
GCSE General Certificate of Secondary Education (taken at 16)
BTEC Business and Technical Education Council (equivalent to GCSE level)
GNVQ General National Vocational Qualification (equivalent to GCSE level)
UCAS Universities and Colleges Admissions Service

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