RESEARCH ARTICLE

Diagnostic Tests: Purposes and Two Case Studies

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Abstract

It is not uncommon to use what are called diagnostic, placement, readiness or competency tests once students arrive at university to gauge their basic skills in mathematics or literacy. This paper begins by discussing diagnostic mathematics tests and identifying the key reasons for which these are run. Two such tests with repercussions for students are discussed. These two tests are for different student cohorts and are run for different reasons. We identify the purposes for which the tests were developed, and actions which eventuated. We identify any additional purposes the tests served beyond those intended. The tests had a positive impact on student learning.

Keywords: diagnostic tests, mathematics support, tertiary mathematics.

1. Introduction and background

In many countries more students than ever before can aspire to a university degree, but an increasing proportion arrives unprepared for the rigors of higher education. One method used to determine the level of basic skills of students beginning tertiary study is diagnostic testing. This paper examines two uses of diagnostic tests that are being applied to try to address the problem of students arriving at university with poor mathematical skills and knowledge. This is preceded by a discussion identifying reasons for which diagnostic tests are used.

Reports from the Organisation for Economic Co-operation and Development (2013) make clear the benefits to individuals and employers, and thus to economies, of higher levels of mathematics and numeracy, along with other basic skills. In Australia, an Australian Industry Group report (2018) states that 39 per cent of businesses are highly affected by low levels of language, literacy and numeracy. Over the last 20 years there has been a huge decrease in the proportion of students choosing calculus based mathematics in Australian secondary schools (Barrington & Brown, 2014) and in the state of New South Wales (NSW) (Nicholas & Rylands, 2015). Despite the importance of mathematics, many Australian universities do not have mathematics requirements for entry into mathematics, science, engineering and other quantitative degrees. There is justifiable concern about what skills students have when they begin university.

In Australia, lecturers rarely have access to students' records of their previous studies. One method used to gain information on the skills that students bring with them to their university studies is to run short diagnostic tests when students arrive at university.

2. Diagnostic mathematics tests

This paper considers mathematics tests which are run once students have been accepted into university. A systematic literature review of interventions that could lead to improved mathematics outcomes for first-year students (Lake, et al., 2017) noted the importance of the mathematical skills students have when beginning tertiary studies and thus the importance of diagnostic tools for determining background and appropriate interventions.

There are many examples of tests or quizzes being run because academics have concerns about the level of knowledge and skills that students bring with them to university. These tests are often referred to as diagnostic tests, placement tests, competency tests, readiness tests or skills assessments. The term diagnostic test, or test, will be used in this section.

Diagnostic tests are run before students start their studies or soon after, providing information on students' prior knowledge. Such tests usually cover basic knowledge and skills. The tests are short; usually less than an hour. These tests are usually not for credit and not all are compulsory. There is enormous variety in the many other dimensions of diagnostic tests.

A UK report (LTSN mathsTEAM, 2003) on mathematics diagnostic testing comprising 13 case studies, began by noting increasingly diverse student backgrounds, which inspired some universities to introduce such tests. The primary aims given for these tests were "to inform staff of the overall level of competence in basic mathematical skills of the cohort they are to teach" and "to inform individual students of any gaps in the level of mathematical knowledge they will be assumed to have—so that they can take action to remedy the situation." On reading the case studies one finds other purposes for which diagnostic tests were used.

At our institution we also use such tests for a variety of reasons. This inspired the first aim of this paper, which is to answer the question

- What are the purposes for which diagnostic tests are used?

A variety of purposes for diagnostic tests appears in the UK report (LTSN mathsTEAM, 2003). For example, at Queen Mary, University of London (QMUL), students were given seven attempts at a test and had to reach a score of 12 out of 15 in order to progress to second year. At the University of Strathclyde students and tutors were given test results and tutors could identify and assist students who were expected to struggle with the work. The University of York used a test to identify any remedial actions needed, and had used the same test in the same manner for 15 years. At Anglia Polytechnic University a test informed students and staff of each student's capabilities. The test gave the lecturer information on the level appropriate for teaching various topics. At the University of Bristol a test informed students what they needed to revise.

Ngo and Melguizo (2016) discuss many issues related to diagnostic tests in American community colleges, including cutoff levels and appropriate placement of students. Their context includes deciding whether or not to place students in remedial mathematics subjects.

At the University of Queensland, Australia, reports of students lacking background knowledge, student dissatisfaction and growth in attrition (Kavanagh, et al., 2009) resulted in a diagnostic test to identify gaps in students' knowledge. The 46 question test covered mathematics, chemistry, physics and thermodynamics. The authors state that the test results will inform plans to support at-risk students in the future. One of the authors' conclusions is that the value of the test may also lie in informing students of gaps in their knowledge; they also report that it was reasonably reliable for predicting success. This test was used for engineering for students at the University of Auckland, New Zealand (Shepherd, et al., 2011), however, here the main motivation was to raise students' awareness of their weaknesses and address these. They found this to be relatively successful, despite being unable to send students individual feedback. Also mentioned was using information gathered by the test to underpin support for students, especially from "Never seen it before" responses.

Wilkes and Burton (2015) report on an online test covering mathematics, among other topics. It was designed for engineering students by a team covering five Australian universities. The increasing diversity of students was a driver for the project. Students received immediate individual feedback which informed them of the skills and knowledge needed for their studies, and they were encouraged to take responsibility for learning. The test was found to be good for predicting success in mathematics even though it was run largely for applied science students.

Espey (1997) used a test to drive improvement in the basic mathematics of students by requiring them to reach a threshold of 84 per cent before the second test of the semester. Students were allowed to sit the test many times, but no more than once a day. Mathematics support was provided to students.

Carr, Bowe, and Ní Fhloinn (2013) report on a test which they refer to as a core skills assessment, run for engineering students at the Dublin Institute of Technology. It contributes 10 per cent to the final mark for first-year students. Students who do not reach 70 per cent in the test receive a contribution of 0 to their final mark, however students are allowed to sit the test many times. Immediately after the test students are given correct answers to questions they answered incorrectly. The aim is to drive learning in core skills.

For business students, Abdullah, Ujang, Ramli, Dzulkifli, and Mohamed in Malaysia (2016) use a diagnostic test to predict performance. They mention also giving teaching staff an overview of student's mathematics capabilities. Silva, Ghodsi, Hassani, and Abbasirad (2016) report on a diagnostic test run in a British university for business, accounting and finance students. The authors state that the results can be used to argue for more mathematics and statistics support and they raise questions about entry criteria.

2.1 The purposes of diagnostic mathematics tests

The previous section provided many examples of different uses of diagnostic tests.

A diagnostic test is assumed to give some evaluation of students' capabilities, but it almost always goes beyond that, as there is then some action by students or staff or both. In a few cases the action goes further, such as requesting resources in order to provide support.

Our summary of the purposes found for the use of such tests is:

(1). Predict performance.

(2). Identify at-risk students, with the aim of providing assistance.

(3). Enable students and/or staff to decide on the right level of subject for each student (in cases where there is a choice).

(4). Require students to reach a determined level of skills in order to progress.

(5). Inform teaching staff about the level of knowledge of students, perhaps enabling them to target their teaching to the level of (most) students.

(6). Inform students of any gaps in their knowledge so that they can then address these.

There is one other important purpose, which involves planning and resources. It is hinted at in some of the literature, but not often stated explicitly:

(7). Inform non-mathematicians and decision makers about the level of mathematical knowledge of students.

These purposes can be found in the papers cited in the previous section. For example, Purposes 1, 2, 5 and 6 in Kavanagh et al. (2009), Purpose 3 in Ngo and Melguizo (2016), Purpose 4 in Espey (1997) and Purpose 7 in Silva et al. (2016).

These purposes are not disjoint. For example, Purposes (2) and (6) are similar, however Purpose (6) has the focus on the student taking action, whereas Purpose (2) has the focus on the institution acting. Purposes (1) and (2) overlap as prediction of performance can be used to determine who is at risk of failing.

Though Purpose (7) is often not explicitly stated, it can be important. Poor mathematics background can lead to higher failure rates, higher attrition and lower eventual attainment. Ngo and Melguizo (2016) note the costs of misplacement and remediation. Thus decision makers and academics should be informed if students lack mathematical skills as this can have negative consequences and so should affect decisions on enrolment, support, curriculum and student advice.

As noted (LTSN mathsTEAM, 2003), a diagnostic test by itself has limited value. It is usually appropriate to follow a test by some action. If the reasons for a diagnostic test include some of Purposes (2), (3), (4) and (6) then the appropriate action is clear; for all but Purpose (3) this includes providing students with resources and support; for Purpose (7) action could include requesting resources for the provision of support (Silva, et al., 2016).

For Purposes (1)–(4) and (6) it is desirable to have every student sit the test, and for Purposes (5) and (7) a high proportion taking the test is needed. Therefore making a diagnostic test compulsory is clearly beneficial, though it could be hard to enforce.

At Western Sydney University (WSU) we found that encouraging students to use resources, or to do extra work to fill gaps in knowledge, was often unsuccessful. We felt it necessary to require students to build skills in order to progress. In the next section we present two case studies of the use of diagnostic tests in which the circumstances and actions for redressing gaps are different. For each case study three questions are viewed through the lens of the preceding discussion:

• What was or were the purpose(s) of the test?

• What actions were taken as a result of test?

• Were the actions successful in addressing the purpose(s) of the test?

3. Two tests

Western Sydney University (WSU) is a large multi-campus university with over 44,000 students in NSW, Australia.

Over the last two decades the proportion of students taking low level, or no, mathematics in the last two years of secondary school has been increasing (Nicholas & Rylands, 2015). In 2017 about two-thirds of students who completed secondary school in Australia and who were enrolled in WSU first-year mathematics subjects had inadequate mathematics backgrounds for their studies. It is therefore not surprising that academics perceive a drop in performance in first-year mathematics and find that many of our students lack very basic mathematical skills.

This situation has inspired some academics to run mathematics diagnostic tests. We report here on two tests which are administered in two mathematics subjects at or near the start of a semester in first year, and for which follow up actions have been monitored. The primary purpose of one test is to decide in which mathematics subject to place students; this will be referred to here as the placement test. The primary purpose of the other test is to inform students of where any weaknesses lie and to address these in order to progress; this will be called the diagnostic test.

3.1 A test for industrial design students

Industrial design students at WSU are often very poorly prepared mathematically, so students sit a diagnostic test early in their first-year basic mathematics subject. The test has three aims:

• to highlight to students any gaps in their basic mathematics, Purpose (6);

• to ensure that students largely address any gaps by the end of the semester, Purpose (4);

• as evidence for non-mathematics academics of the level of students' skills, Purpose (7).

In 2016 approximately 70 first-year industrial design students enrolled in their mathematics subject. As it can take considerable time to gain missing skills, and as students usually focus on assessment tasks during semester, students were required to reach a threshold of 11 out of 14 in the diagnostic test in order to pass the subject. To keep students focussed on improving their basic skills until they reached the threshold, six attempts throughout the semester were allowed. A slightly different test was used for each attempt. The test contributed 10 per cent to the final mark for the subject. Students who did not reach the threshold during the semester failed the subject, regardless of their total mark.

Before the first test was run students were given a sample test in class which they marked themselves.

The diagnostic test was a 14 question paper-based short answer test for which students were given 12 minutes. Almost all students gave an answer for each question, but for a few students the time allowed for the test was too short, so the following year the time was increased to one minute per question. Topics covered were basic fraction calculations, order of operations, multiplication and division by powers of 10, conversion of units, percentages, decimals and basic algebra. The topics were chosen based on common errors, such as errors with basic algebra and very simple calculations with fractions. A learning outcome for the subject included "specify and manipulate quantities, units and scale reliably and accurately" so change of units and proportional reasoning were included.

The use of calculators was not permitted as this made it easier to test basic fraction calculations and order of operations. Where calculations had to be done, the numbers involved were kept small. For example, to test addition of fractions students were asked to find 2/3 + 3/5 in the first test.

Marked tests were returned to students. Students were offered support including workshops to build skills, face-to-face drop-in help and online resources.

3.2 A test for engineering students

A decade ago, students enrolling in engineering were expected to have a reasonable knowledge of calculus of one variable. The subject Mathematics 1 made this assumption and reviewed calculus in the first few weeks before moving on. With students coming to university with lower levels of secondary school mathematics, this subject proved too difficult and a new subject, which we call here Preliminary Mathematics, was introduced in 2010. This new subject revises basic algebra, trigonometry and the theory of functions before introducing differential and integral calculus in the second half of the semester.

Initially, all new students were enrolled into Mathematics 1 and were encouraged to attempt a placement test comprising 50 multiple choice questions on topics from the assumed knowledge (exponents, factorisation, linear equations, surds, exponential and logarithmic equations, trigonometry, functions, graphs, differentiation and integration). The topics included in this test were felt to reflect those topics covered in high school mathematics which students who could expect to be successful in the Mathematics 1 subject should be familiar with before commencing their university studies. Students achieving less than 70 per cent in this test were recommended to switch to Preliminary Mathematics before attempting Mathematics 1. However, this did not have the desired effect as many students were reluctant to move to Preliminary Mathematics.

All new students are now enrolled in the preliminary subject and must obtain at least 70 per cent in the placement test in order to bypass it. Some aspects of this test are discussed in Rylands and Shearman (2018), although from a different point of view.

Students are given 50 minutes for the placement test and are allowed to use a calculator. As this test is essentially an aptitude test in mathematics it was felt that one minute per question should be adequate time for a student who had the required cognitive ability for Mathematics 1. This has meant that students who attempt the test without the necessary capabilities often do not complete all questions in the test. It was decided to allow the use of a calculator for this test as the focus of the test is students' mathematical reasoning capabilities and the numerical calculations are of less importance overall. In addition, the use of calculators in engineering is standard practice. The test is run in university computer laboratories, and is supervised. Running the test online means that marking is automated, so despite the large cohort, students receive their results quickly, enabling them to finalise their enrolment. The test software selects numbers from predetermined ranges for each student, minimising the possibility of cheating. As the aim is to determine students' underlying capabilities, no practice or sample tests are provided before the test is run.

The aim of the placement test is to determine which mathematics subject new engineering students will take; Purpose (3).

4. Outcomes of the tests

In this section the actions and consequences of running the tests are presented, shedding some light on the questions posed earlier about these tests.

4.1 The mathematics diagnostic test for industrial design

When the test was first run 94 per cent of enrolled students completed the test; of these, 55 per cent did not reach the threshold. The test revealed that almost a quarter of students could not change a simple measurement from metres into centimetres and over a third could not evaluate $-6 + 4 \times -5 - 3$. The easiest question, which 88 per cent of students did correctly, was to arrange from smallest to largest 0.702, 0.072, 0.72, 0.0702. The question that students performed most poorly on, with only 41 per cent giving the correct answer, was on simple proportional reasoning. This was usually the case each time the test was run; overall there was no change in what was found to be difficult by students who sat the test many times.

The test was informative for teaching staff, who did not know the extent of students' mathematical gaps, Purpose (5). The information was passed on to decision makers and other academics to increase their understanding of the level of mathematical skills of students, Purpose (7).

Special workshops were run for students who had not reached the threshold, helping them to address problems, Purpose (6). Mathematics support staff discovered that some students did not know where the decimal point belongs in an integer, further addressing Purposes (5) and (7). Discovering such aspects of students' knowledge was an indirect result of testing.

With regards to the purposes for which such tests are run, this test addressed Purposes (4), (5), (6) and (7), with the main reason for the test being Purpose (4).

Of the 61 students who were still enrolled at the end of semester, all had attempted the test at least once. Eleven never reached the threshold; none of these students would have passed the subject, even if they had reached the threshold. Of the 50 students who reached the threshold, only three completed the subject (sat the final exam) with a fail grade. Those who did not reach the threshold all had final marks less than those who did, thus the test partly addressed Purpose (1). That several students who reached the threshold failed the subject raises the question of whether the threshold should be increased.

The test was successful in its primary purpose, Purpose (4), in that a noticeable number of students spent time working on basic skills during the semester until they reached the threshold, with many more students than usual attending support workshops and staff consultations. Not all reached the threshold, but they did noticeably improve. Multiple tests have proved to be motivational in other technical disciplines (Davis, et al., 2005; McLoone, 2007).

The extra work of running and marking a test every two or three weeks was minimal. An advantage of a written test is that staff could read the working and so gain some insight into students' misunderstandings.

4.2 The mathematics placement test for engineering

Students who score less than 70 per cent in the placement test must pass the subject Preliminary Mathematics before attempting Mathematics 1. The introduction of the preliminary subject and the requirement for students to pass the placement test to gain direct entry to Mathematics 1 has resulted in a reduction in the failure rate for Mathematics 1 and a reduction in the number of students who fail this subject multiple times. The failure rate for Mathematics 1 was previously regularly above 40 per cent with occasional peaks at over 50 per cent; it is now typically about 30 per cent. Thus the test has to some extent fulfilled its aim, Purpose (3).

The failure rate for Preliminary Mathematics remains at about 40 per cent. Of this 40 per cent about half failed at least one other subject in the semester, suggesting that students who are not successful with the placement test often have other gaps in the knowledge required to complete an engineering degree.

There is interest in raising the score needed for entry to Mathematics 1, however, before that is decided, data on placement test scores and grades in Mathematics 1 needs to be analysed.

Two side effects of running the placement test are that staff have found it provides useful information about students' capabilities, Purpose (5), and it is a strong predictor of success in Preliminary Mathematics, Purpose (1).

5. Discussion and conclusion

The literature gives many reasons to use diagnostic tests. The seven purposes listed earlier cover the purposes found in the literature and reported here for conducting diagnostic tests, apart from making students feel "looked after". Information about students and student cohorts gained from running diagnostic tests can be used in a variety of ways to improve learning, as seen from the various purposes of such tests.

The weak mathematical backgrounds of students is a common concern in the literature, with some also mentioning the related problem of increasing mathematical diversity (Kavanagh, et al., 2009; LTSN mathsTEAM, 2003; Wilkes & Burton, 2015). The diagnostic and placement tests discussed here are used to improve basic skills or to direct students to subjects in which they can gain basic skills. A consequence of the tests is a reduction in the mathematical diversity of the cohorts.

Beyond the placement function of the test in engineering (Purpose (3)), students have access to their test results on a question by question basis, which could be used to guide students to resources targeting their problems; there is potential for Purpose (6). Academics teaching Preliminary Mathematics and mathematics support staff have access to the test results by question and student, making it possible to find the areas in which students have gaps. Resource shortages have not allowed this data to be used to its full advantage, improving Purposes (5) and (6). Shepherd et al. (2011) also noted an inability to make full use of information gained from test results.

The main aims of the industrial design test were Purposes (4), (6) and (7), different to those of the engineering test. Students saw where mistakes occurred, and many used resources and workshops provided to improve their test mark. Support staff were guided by the test results in the creation of workshops for these students.

Though the two WSU experiences were different, in each case purposes beyond the original could be served by the testing. Both tests were deemed to be a success, with academics finding that designing, running and marking the tests was time well spent. Success is reported elsewhere (Kavanagh, et al., 2009; Shepherd, et al., 2011), in particular with Purposes (5) and (6), and both planned to run the tests again. In the USA, the continued and entrenched use of such tests demonstrates that they are considered useful (Ngo & Melguizo, 2016).

A common feature of the two WSU tests is that both attempt to enforce action. In the past, engineering students were advised about the right choice of mathematics subject; now they do not get a choice. Failure rates improved when the choice was removed. For the industrial design students, not allowing students to progress until they have reached the threshold motivated students to improve their basic skills, and those who reached the required level mostly passed the subject. Setting a threshold was also found to be successful by Espey (1997) and at QMUL (LTSN mathsTEAM, 2003).

Support and resources for students are important when a test is run for Purposes (2), (4) and/or (6) as these enable students to take action to improve.

The levels required for each of the WSU tests discussed here are in question; perhaps they need to be raised. The difficulty of diagnostic tests or levels required are not discussed much in the literature. Analysis of relevant data is needed so that good decisions are made.

The experience of the two WSU tests and in some of the literature is that useful data can be collected when diagnostic tests are run, and that purposes other than the initial ones can be served, leading to better learning outcomes. There is scope for research and improved learning by using data related to diagnostic tests, both for mathematics and for other disciplines.

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