Predicting university performance

S. I. Barry[1] J. Chapman[2]

(Received 9 July 2007; revised 11 September 2007)

Abstract

University admissions in Australia are dictated primarily by entrance ranking scores (TER) based on all courses taken in secondary school. However, these are unreliable indicators of ability to do mathematically based university courses. Differences in mathematical curricula between Australian states also complicates admissions for students moving interstate, especially with 19 or more different mathematical courses being offered in high schools across Australia. This article compares student TER and performance in a diagnostic test, against their university grade at the end of one semester to find a better predictor than simple TER measures.

Contents

See http://anziamj.austms.org.au/ojs/index.php/ANZIAMJ/article/view/304 for this article, Published October 7, 2007. ISSN 1446-8735

1 Introduction

Admission to Australian university courses is biased by a student's entrance rank (TER, UAI, ENTER). This score is based on overall high school performance and measures their approximate percentile ranking. Each of the seven states (and territories) of Australia have different education systems, methods of calculating this rank, and offer two or more mathematics courses [2]. This gives rise to over 19 different school mathematics curricula and five different grading structures making admission policy to mathematically based courses difficult with many students moving interstate.

UNSW@ADFA is unique in getting students from all over Australia, with a bias towards the more populated states of New South Wales (NSW), Queensland (Qld) and Victoria (Vic). This causes difficulties in deciding admission and designing mathematics courses with, for example, some states not covering matrices and others not covering complex numbers.

In 2006 we gave our incoming first year science and engineering students a 50 minute, multiple choice test, based on basic, pre-calculus, mathematics—with an emphasis on basic algebra. The results of this test were then compared with the student's TER, the high school course the student took, and their grade at the end of the final semester. Our aim is to find a better pre-

Table 1: Sample size by state and course. NSW 3 and 4 unit mathematics courses are denoted 'high' level courses but are separated here as 4 unit/3 unit.

		ACT	SA	WA	NSW	Vic	Qld	Tas
Science	high	0	2	2	1/10	6	7	3
	low	1	2	0	8	8	6	0
Engineering	high	0	3	5	3/7	15	26	2
	low	1	4	0	4	6	10	1

dictor of student performance than TER. In 2007 we used this predictor to stream students, provide help to students deemed at risk, and to give career advice.

UNSW@ADFA is a defence force academy combining university education with military training. Students are admitted using Australian Defence Force selection criteria. The level of support given to students is higher than at other universities, with higher staff-student ratios and smaller class sizes. This may bias our results, but with a wide enough range of applicant abilities, we do not think this is the case. We offer two 13 week first semester, first year, courses in mathematics: a science course to 80 students with 52 lectures, 26 tutorials; and an engineering course to 120 students with 52 lectures and 13 tutorials. Both courses offer small weekly assessment, mid-session tests, and a heavily weighted final exam. Both courses are roughly similar to other first year university mathematics courses, covering one dimensional calculus (differentiation, integration, Taylor series), first order differential equations (modelling, separation), and algebra (complex numbers, vectors, matrices). The science course is easier than the engineering course, reflecting the lower TER scores of incoming students. The precise breakdown of students is given in Table 1. For simplicity, NSW 3/4 unit students are combined as high level students, although further study with a greater sample set is required to ascertain the difference these two courses have on university performance.

Diagnostic testing of incoming university students is practised by many universities in the UK and USA [9, 11, 13]. An Engineering Council (UK) report [7] recommended to all universities that students entering university mathematics courses should have a diagnostic test on entry. In California, many campuses [12] give diagnostic tests to incoming students, and have a program allowing secondary schools to use these tests to better prepare their students. Diagnostic tests identify weak students, educate university staff in actual student abilities, allow targeted appropriate remedial help, and help design curricula. The need for these tests indicates that the secondary education system is not preparing students for university and is not trusted by universities. In Australia this is complicated by our fractured education system, although the same problems exist in the UK which has a national education curriculum.

The increased usage of diagnostic testing is due to the perceived decrease in student mathematical abilities [6, 8, 10, 14, 15, 16, 17] and a measured decrease in higher level school mathematics participation rates [1]. In the UK several longitudinal studies have been done using the same diagnostic test over several years to benchmark incoming student ability [10, 18], showing a consistent decline in student ability from 76% average mark to 50% average mark for their diagnostic test from 1986 to 1997.

In 1998, Catchpole and Anderson [5] compared NSW and Victorian students entering UNSW@ADFA finding that Victorian students under-performed against NSW students with the same TER, by 5–10 marks in calculus, but that there was no difference in algebra. Students doing higher level mathematics courses did 10 percent better at both algebra and calculus than those doing lower level mathematics. A student with a TER of 95 from Victoria performed much the same as a NSW student with a TER of 90.

In this article we first discuss the diagnostic test, then the differences between our science and engineering courses before analysing results to find better predictors of student university performance.

2 Diagnostic test

The diagnostic test was written by Dr Mark Nelson, University of Wollongong, based on an Essential Mathematics Scheme developed at UNSW@ADFA in 1995 [3, 4]. The closed book test is given in the first week of classes and comprises 20 multiple choice questions. Students are made aware of the test during enrolment, and rough content, but do not study for it as the test does not count towards their final grade. The questions are as follows with multiple choice answers omitted:

1. Simplify $\frac{(x^2)^3 \times x^{-2}}{x^3}$.
2. $\sqrt{a} - 3\sqrt{b} + \sqrt{4a}$ is equal to …
3. If $f(x) = 3x^2 - 5x + 4$ and $g(x) = 2x + 10$ then $f(1) - g(-1)$ equals …
4. The equation of the line between $(1, 2)$ and $(-1, 3)$ is …
5. $\log_2 8$ is equal to …
6. The expression $(x - y)^2 - x^2$ can be written more simply as …
7. $\frac{1}{a+b}$ is equal to …
8. $\frac{x^n}{x^{n-1}}$ equals …
9. Rearrange the following equation to find y: $\frac{1}{x} + x = \frac{1}{y}$.
10. The expression $3m(m - 1) - 2(m^2 + 2m + 5)$ can be written as …
11. Given that $f(x) = x^2 + 3 + \frac{1}{x^2}$ which of the following statements is true: i) $f(a) = f(-a)$, ii) $f(a) = -f(a)$, iii) $f(a) = f(a^2)$, iv) $f(a) = 0$, v) none of above.

12. The domain of the function $f(x) = \frac{1}{\sqrt{1-x^2}}$ is ...
13. Geometrically the equation $x^2 + 2x + y^2 = 0$ describes ...
14. The expression $\log_a(xy^2) + \log_a(yz^2) - \log_a(xz^2)$ simplifies to ...
15. The values of x which satisfy $|3x - 4| < 2$ are ...
16. Given x on the interval $0 \leq x \leq 2\pi$ such that $\sin x = \frac{1}{2}$ then x is ...
17. Find the roots of the quadratic $x^2 + 1 = 5x$.
18. Simplify $2^a 4^b$
19. If $\ln a = 2$ and $\ln b = 3$, evaluate $\ln(ab^2)$.
20. The expression $\frac{1}{\cos^2 x} - \tan^2 x$ can be simplified to give ...

3 Science and engineering courses

Both science and engineering courses have a final grade percentage with mean of 60 and a standard deviation 19. When we use simple linear regression to model the relationship between final grade and the diagnostic test we gain different models for both science and engineering students. The regression equations are

$$F_s = 32.25 + 2.9T\,, \quad F_e = 22.70 + 2.81T\,, \tag{1}$$

where F_s, F_e denote the science and engineering results and T denotes the diagnostic test result. The two equations are practically parallel and show science students gaining approximately 10 marks more than similar engineering students, reflecting that the science course is perhaps easier, being aimed at weaker students. Figure 1 shows the data and two regression lines with a ten mark reduction for science students. Whilst not ideal, this rescaling allows us to pool the data in this exploratory analysis to eliminate some small sample size problems.

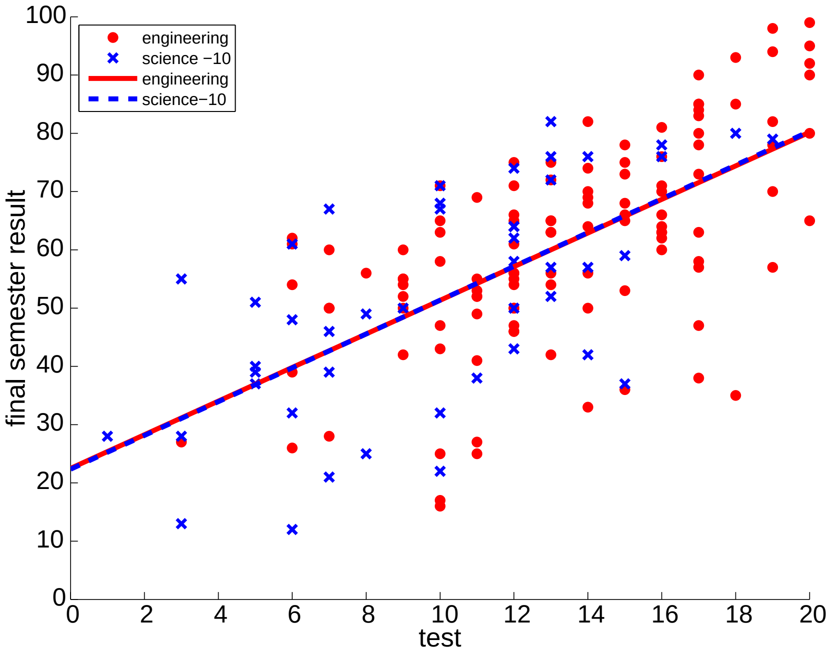

Figure 1: Final semester 1 results for science and engineering courses versus diagnostic test with 10 marks subtracted from the science grade.

4 Results

Since university admissions are usually based on TER, we looked at final performance in semester 1 at university by TER, as illustrated in Figure 2. As expected, there is a positive relationship between TER and final results, but with a R^2 value of only 26.8%. The relationship is not as strong as that between diagnostic test and final result which has R^2 equal to 43.5%. This is expected since TER includes other, non-mathematical subjects, in its calculation. Each state normally offers two or three high school mathematics courses, which we broadly classify as either a high level or low level course. Figure 2 for example, illustrates the students doing a higher level mathematics course in NSW, with their regression fit. To be able to simply compare state courses we consider a typical student with TER of 90 and use the regression line to predict their final semester result. Hence a NSW high level mathematics student would be expected to get 68 in their university course.

The current system of university admission considers only TER and is essentially based on a prediction formula for our student's final semester 1 mathematics grades, F, of

$$F = -54.2 + 1.25\,\textsc{ter}, \quad R^2_{\text{adj}} = 26.2\%\,. \tag{2}$$

If our diagnostic test is also included, then

$$F = -24.1 + 0.61\,\textsc{ter} + 2.2\,\textsc{test}, \quad R^2_{\text{adj}} = 45.3\%\,, \tag{3}$$

with significantly greater predictive power as indicated by the adjusted R^2 value. If the level mathematics course at school is considered, then

$$F = -36.3 + 1.08\,\textsc{ter} - 9.17\,\textsc{low}, \tag{4}$$

where LOW indicates a student who has done a low level school mathematics course. Hence, students who have done low level mathematics at school perform 9 percentage points lower than a student with the same TER but who

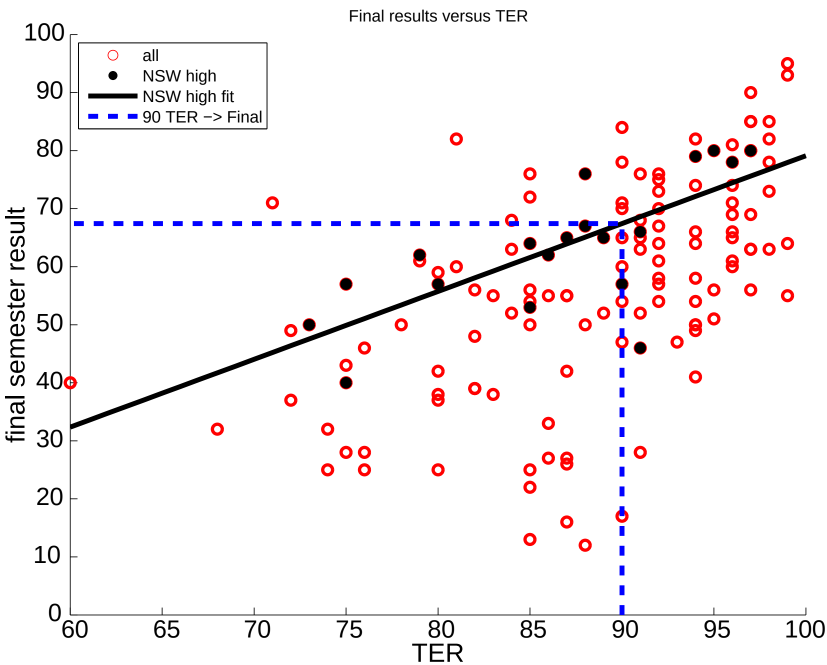

Figure 2: Final result versus TER with students doing the NSW high level courses indicated.

has done high level mathematics. This could be due to the more interested and able mathematical students doing high level mathematics, or a direct response to the extra mathematical exposure in high school.

Results are expanded to include state of origin and a stepwise regression analysis revealed the optimal model, and the only statistically significant result, is the predictive formula

$$F = -59.8 + 1.37\,\textsc{ter} - 11.4Q_h - 18.0Q_l\,, \tag{5}$$

with $R^2 = 39\%$, $R^2_{\text{adj}} = 37.5\%$ and Q_l, Q_h the Qld low and high level courses. If diagnostic test is also included, a further step-wise analysis results in the optimum model

$$F = -33.8 + 1.73\,\textsc{ter} + 0.814\,\textsc{test} - 7.04Q_l - 9.20Q_h\,, \tag{6}$$

with $R^2 = 48.3\%$, $R^2_{\text{adj}} = 46.6\%$. This result shows that there is no significant difference between state systems with the exception of Queensland, whose high-level students lose 11% compared to students from other states with the same TER, and whose low-level students lose 18% compared to students from other states with the same TER. Remarkably, even when diagnostic test is included, Qld students are still at least 7 marks worse off than their colleagues from other states; their mathematical weaknesses extend to mathematics beyond the essential skills of the diagnostic test.

In Table 2 predictive results for a student with TER of 90 are shown, using the predictive formula without diagnostic test result since this is unavailable during university admission. Hence the table shows that mean final semester result of Qld high level students with TER of 90 is 52, and we are 95% confident the mean is between 47–57%. But an individual high level Qld student with a TER of 90 could get a score in the range 22–81 with a 95% confidence interval.

Table 2: Predicting university results based on a student with TER of 90 without diagnostic test. The predictive mean, confidence interval and predictive intervals are shown.

State	course	Mean	95% CI	95 % PI
Qld	low	45	(37–53)	(15–76)
Qld	high	52	(47–57)	(22–81)
Other		63	(60–66)	(33–93)

5 Conclusions

There are two main conclusions from this work. First, students doing higher level mathematics courses at university get roughly 9 more marks at university mathematics than their colleagues doing lower level mathematics, despite having the same TER. Second, Qld students are underperforming in our mathematics courses, losing 11 percent relative to their colleagues from other states with implications on our admission policies. This result may be due to the official formula used to translate the Queensland OP ranking system to the TER ranking system, that the Qld system is teaching mathematics we do not use in our courses, or that the Qld system does not teach enough mathematics. We cannot preclude the possibility that Qld students are being taught other important skills that we do not test in first year mathematics. We also note the restrictions of this study to a small sample of only one year's group of students and a lack of students in some of the categories. However, our preliminary results do indicate the need for some coordinated examination of school curriculum performance across Australian states. We intend to extend this analysis to include 2007 students and their performance in related mathematically based subjects like physics.

In the absence of a national curriculum or testing system, we believe the use of diagnostic tests and analysis such as in this article, can be used to find better predictor formula for university admission to mathematically based courses.

References

[1] F. Barrington and P. Brown, Comparison of Year 12 pre-tertiary mathematics subjects in Australia 2004–2005. *Australian Mathematics Science Institute,* 2005. http://www.ice-em.org.au/images/stories/FileDownloads/Comparison_of_Year_12_Pre-tertiary_Mathematics_Subjects_in_Australia_2004-2005.pdf C39

[2] F. Barrington, Participation in Year 12 mathematics across Australia 1994–2005. *ICE-EM Publications in Education No 2,* Australian Mathematics Science Institute, 2006. http://www.ice-em.com.au/pdfs/Participation_in_Yr12_Maths.pdf C37

[3] S. I. Barry and S. Davis, Essential mathematical skills for undergraduate students. *Int. J. of Math. Education in Science and Technology*, **30**, 499–512, 1999. C40

[4] S. I. Barry and S. Davis, Essential Mathematics Skills, *UNSW Press*, Australia, 2002, C40

[5] E. A. Catchpole and B. R. Anderson, Comparing the performances of NSW and Victorian students in a first-year mathematics course. *Austr. New Zealand J. Statist.* **40(4)**, 1998, 389–406. doi:10.1111/1467-842X.00044 C39

[6] A. C. Croft, S. Hibberd, D. A. Lawson, L. R. Mustoe and C. T. Shaw, Engineering mathematics in the UK: SARTOR—a timely opportunity for reform. *Engineering Science and education Journal.* 2000, 77–87. doi:10.1049/esej:20000205 C39

[7] Engineering Council (UK), Measuring the Mathematics problem, *Engineering Council*, June 2000. http://www.engc.org.uk/publications/pdf/mathsreport.pdf C39

[8] M. S. Fadali, N. Velasquez–Bryant and M. Robinson, Work in progress—Is attitude toward mathematics an obstacle to engineering education? *4th ASEE/IEEE Frontiers in Education Conference*, 19–24, 2004. http://fie.engrng.pitt.edu/fie2004/papers/1090.pdf C39

[9] B. Hassler, R. Atkinson, D. Quinney and M. Barry, The Experience of Fresher Students in Mathematics Diagnostic Testing, *MSOR connections*, Aug 2004, **4**. http://www.atm.damtp.cam.ac.uk/people/bh213/ARDTS/DiagnosticTesting_MSOR_aug04.pdf C39

[10] D. Lawson, Changes in student entry competencies, 1991–2001. *Teaching Mathematics and its applications,* **22(4)**, 171–175. doi:10.1093/teamat/22.4.171 C39

[11] Ltsn, MathsTEAM Project, Diagnostic testing for mathematics, http://mathstore.ac.uk/mathsteam/packs/diagnostic_test.pdf C39

[12] MDTP, Mathematics Diagnostic Testing Project, *California State University,* http://www.math.csusb.edu/mdtp/Home.htm C39

[13] A. Miller, J. Bradbury and D. Middleman, Diagnostic testing, *Mount Allison University, USA.* http://mathcs.mta.ca/demo1.htm C39

[14] I. E. Otung, Reassessing the mathematics content of engineering education. *Engineering Science and education journal,* 2001, 130–138. doi:10.1049/esej:20010401 C39

[15] J. Ridd, Participation in Physics and rigorous mathematics and a consideration of educational, economic and political influences. PhD Thesis, *James Cook University*, 2003. C39

[16] J. Ridd, Year 9 and 10 structures in Queensland and possible implications for subsequent studies in Mathematics and Physics. *The Physicist*, 37(3), 94–98, 2000. C39

[17] P. Ridd, Physics will add up only with maths. *The Australian*, July 19, 2006. p.32. C39

[18] K. L. Todd, An historical study of the correlation between GCE Advanced level grades and the subsequent academic performance of well qualified students in a university engineering department. *Mathematics Today*, **37(5)**, 2001. C39

Author addresses

1. **S. I. Barry**, School Physical, Environmental & Mathematical Sciences, University of New South Wales at ADFA, Canberra, Australia.
   mailto:s.barry@adfa.edu.au

2. **J. Chapman**, School Physical, Environmental & Mathematical Sciences, University of New South Wales at ADFA, Canberra, Australia.