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Mathematics: A powerful pre- and post-admission variable to predict success in Engineering programmes at a University of Technology

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Although student attrition and retention are researched all over the world, there is no final formula available to ensure academic success for selected students. The purpose is to share research undertaken at the Tshwane University of Technology (TUT) in order to investigate the role of mathematics in student achievement and retention in National Diploma engineering programmes. This study contributes to the identification of key aspects that exercise an influence on success at a University of Technology (UoT) in a country where students have diverse schooling experiences. An ex post facto study was carried out on a sample drawn from the first-time-entering National Diploma cohorts of 2009 and 2010 to determine a possible correlation between their National Senior Certificate (Grade 12) mathematics performance and their first semester mathematics performance, or with their first semester mathematics performance and the number of subjects passed after two years of study. The results indicate that the performance in Mathematics I has a better predictive value than any other variable investigated. The performance in Mathematics I may therefore be used as part of an early warning system for dropping out and in determining the size and nature of the support structures needed. Mathematics performance during the first semester at TUT is a significant determinant of academic success for National Diploma students in engineering disciplines.

Keywords: admission, selection, higher education, mathematics, prediction of success, academic exclusion

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Background

Due to unequal academic provisioning (Nunns & Ortlepp, 1994; Bitzer, 2010) in South African schools, some students arrive at higher education institutions without the necessary abilities to succeed. Different universities developed differing strategies for selection (the process to determine admission) and placement (the process after admission to determine the mainstream or extended programme) of students based on the factors for non-performance identified by such institutions (Visser & Hanslo, 2005). Some authors suggest a combination of instruments rather than just one (Jackson & Young, 1988; Ochse, 2003; Jama, Mapesela & Beylefeld; 2008; Grussendorff, Liebenberg & Houston, 2004).

The slogan "access for success" (if you enrol a student he/she should have a fair chance of succeeding in his/her studies) became relevant as it was soon evident that an increased intake of previously disadvantaged students would not automatically result in more graduates (Couglan, 2006; Jama, Mapesela & Beylefeld; 2008; de Beer, 2006), despite the best intentions of the Education Department. Although the Faculty of Engineering at TUT performed admission tests, which were regarded as an enabling process and not a gateway to keep students out (Koch, Foxcroft & Watson, 2001), such tests were abandoned by the top management of the university in 2008 in many disciplines as they were perceived to restrict access. This situation necessitated the use of other means to determine students who need extra support in order to facilitate their progress. In the said faculty we therefore, with new interest, investigated models using readily available pre- and post-admission variables to determine and establish student success patterns. Some of the factors that were found to influence student progress, not related to an admission test to determine cognitive and non-cognitive potential, will now be discussed.

School performance and National Senior Certificate (Grade 12) Mathematics

Although Zhang, Anderson, Ohland and Thorndike (2004) determined that the High School Grade Point Average (HSGPA) was a significant predictor of student success, the same might not be true in South Africa. The changes in the school syllabi for the National Senior Certificate (the final National examination written at the end of Grade 12, hereafter referred to as NSC) and the introduction of outcomes-based education in schools after the abolishment of apartheid were not received well by higher education institutions (Jansen, 2012). Students tend to arrive at higher education with less knowledge than before and this is especially true for mathematics (Engelbrecht, Harding & Phiri, 2009; Louw, 2009; Rademeyer, 2009; Mustoe, s.a.). In 2008, when the first of these NSC examinations was written, it was found that of the 592 000 learners who wrote the mathematics exam in 2008, only 4% had passed with more than 50% (Rademeyer, 2009; Klopper, 2009). The general conclusion in the literature is that the NSC is not a reliable predictor of academic success (Van Eeden, De Beer and Coetzee, 2001; Grussendorff, Liebenberg & Houston, 2004); hence some authors suggest that in order to access students for success (Visser & Hanslo, 2005), institutions have to develop alternative tests in order to select appropriately.

English communication skills

South African students are required to study in English at most Higher Education Institutions (HEIs), but English is seldom their mother tongue. The majority of them have received schooling in English from a certain age, but code switching (Setati & Adler, 2002), the practice where teachers would explain concepts in the learners' mother tongue and switch between English and another language as needed, allowed them to progress despite their language barriers. Acknowledgement of these barriers has been communicated through research at many South African institutions (Owino, 2002; Van Rooyen, 2001; Mumba, Rollnick & White, 2002). Agar (1990) found that language barriers were ranked the number one obstacle by 75.3% of first year students at the University of the Witwatersrand, one of the top ten universities in Africa. Determining the predictive value of the NSC English score for success in engineering studies at UoTs is therefore of importance.

Mathematics as a phenomenon

The teaching and learning of mathematics on all levels have been investigated by many scholars. Cardella (2008) proposed that educators should not only change the mathematical content during educational reforms, but should rather teach mathematical thinking. Gainsburg (2006) advocates the inclusion of modelling in school syllabi and argues that it would assist engineering students, but realised that many of those in-class activities are not authentic enough to add value. Booth (2004:24) explains the need for "developing capabilities for the future which go beyond mathematics in the curriculum, and towards mathematics in the experienced world of engineering". She sees the need to teach mathematics for understanding, not only for passing a module. At the Tshwane University of Technology (TUT) we offer engineering mathematics to students, but since all disciplines follow the same curriculum in their first two years of study, applications are varied and not only focussed on a student's particular field of study. It was found in international literature that mathematics SAT scores correlate positively with graduation (Zhang, Anderson, Ohland & Thorndike, 2004), but since students in South African public schools do not take the SAT, the predictive value of the NSC Mathematics score is of particular interest.

Non-cognitive aspects

The prediction of retention in engineering studies focussing on non-cognitive aspects has been studied by many (Immekus, Maller, Imbrie, Wu & McDermott, 2005; Lin, Reid Imbrie, 2009; Lin, Imbrie, Reid & Wang, 2011). Although we recognise the value of all those results, we focussed on available academic data and conducted an ex post facto study.

Institutional and other factors

At TUT the Engineering student body roughly reflects the demographics of the country. We acknowledge the fact that the institution is not featured on the Academic Ranking of the World University's list of 2010 (ARWU, 2010) and would therefore not attract the best students. In fact, our students from previously disadvantaged groups would primarily also be from low SES groupings (Bitzer, 2010; Clark, 2007) (in Bitzer). In our quest to widen our access, we need to increase our support to enable students to achieve their academic goals. Our obligation is not over once students are admitted. Student success is linked to how well students make use of existing opportunities (Grussendorff, Liebenberg & Houston, 2004), but then we, the HEIs, have to supply those opportunities. We therefore have to continuously monitor student progress in order to supply students with needed support. Identifying one or more post admission variables that could serve as an *early warning signal* that a student in a UoT engineering faculty needs additional support, is therefore essential. Since the most obvious common denominator among all UoT engineering programmes during the *first semester* of study is Mathematics I, the predictive value of early performance in this subject was of particular interest to this study.

Purpose

The purpose of this study is to investigate the role of mathematics in student achievement and retention in National Diploma engineering programmes. As indicated, student attrition and retention are researched all over the world and there is no final formula available on how to ensure academic success for selected students. This paper contributes to that field by, surprisingly, showing that for engineering programmes at South African UoTs, achievement in Mathematics before a student enters the university and *particularly the performance in Mathematics during the first semester of study* have an exceptionally strong predictive value.

Method

Research questions

To investigate the role of mathematics in student achievement and retention in National Diploma engineering programmes at TUT, we formulated the following research questions:

1. What is the relationship between NSC Academic Potential Score (APS), Physical Science, English and Mathematics scores and academic performance during the first two years of the National Diploma for engineering students ?; and
2. What is the relationship between Mathematics results *during the first semester* and academic performance *during the first two years* of the National Diploma for engineering students ?

Setting and participants

This study was conducted in the Faculty of Engineering and the Built Environment of TUT, South Africa. Participants in this study were 456 first year students from the 2009 first-time-entering National Diploma cohort and 274 first year students from the 2010 first-time-entering National Diploma cohort. The data of 710 students were therefore available for the analysis of academic performance during the first year of study. All first year engineering students were included in the sample except those who completed the NSC before 2008, international students, and 2010 second semester entrants.

Currently students interested in studying engineering at a South African University of Technology first enrol for a three year National Diploma. After successfully completing this Diploma, deserving students can add another year of full-time study to obtain the Bachelor of Technology degree. The Engineering Council of South Africa, which is a co-signatory of the Dublin and Sydney accords, accredits these qualifications, resulting in international recognition in co-signatory countries. The National Diploma comprises two years (four semesters) of theoretical study and one year (two semesters) of industry placement. Since the ideal is for all students to complete the theoretical part of the National Diploma in the minimum time, the number of subjects passed after four semesters (expressed as a percentage of the total number of subjects) is of particular interest to this study. Students on average are required to complete 24 theoretical subjects; to gain this Diploma they must achieve at least 50% in their final mark that is made up of a semester mark, called a predicate, and a final examination.

Mathematics I, a first semester subject, is compulsory for all engineering students at South African UoTs. The subject content of Mathematics I entails a revision of critical work such as exponents, logarithms and trigonometry (which should have been covered thoroughly during high school, but which are lacking for many students). Other topics include functions, i.e. hyperbolic, modulus and inverse functions, the binomial expansion, matrices and vectors, complex numbers (for all diplomas except geomatics and civil engineering which do mensuration and data handling) and differentiation and integration.

Independent variables

National Senior Certificate results

The Mathematics, Physical Science and English scores, as well as the Academic Potential Score (APS), i.e. the aggregate of all NSC subject scores excluding Life Orientation, were used.

Mathematics I

The final results for Mathematics I, a first semester subject in the South African UoT National Diploma engineering curriculum, were used.

Mathematics I predicate score

The final Mathematics I exam *admission* score, reflecting performance during the first four months of the semester, and counting 50% of a learner's final score, was also used.

Dependent variables

The percentages of subjects passed after the first and second years of study were used as dependent variables. The students who did not succeed in passing more than 50% of the prescribed subjects for a particular year of study at TUT are forced to withdraw (academic exclusion). For the purpose of our study we have not excluded students from our sample who withdrew before the end of the period under investigation, since the ultimate aim of this study is to identify such students. The percentage of total subjects passed reflects the number of subjects passed out of the total number of subjects prescribed for the full period (differs between disciplines, but on average 24, as indicated).

Data analysis

In summary we wish to identify which independent variable(s) (NSC results, Mathematics I predicate score, and the final score for Mathematics I) might serve as predictors for academic success during the first two years of study as measured by the dependent variables (percentage of subjects passed after the first and second years of study).

All analyses were conducted using MATLAB version 7. Significance tests were first conducted to determine which independent variables are significantly different for the group of students who passed more than 50% of the curriculum during the first semester, and those who failed more than 50%. Both the two-sided *t-test* and bi-variate logistic regression were used. Where appropriate the Wilcoxon rank sum test was also performed to verify the results of the two-sided *t-test* since there were concerns that not all independent variables were normally distributed. Pearson correlation was performed to determine if there is a significant correlation between an independent variable and the percentage subjects passed after one year. Stepwise linear regression, a step by step iterative construction of a linear regression model to find the combination of independent variables that best explain the dependant variable, was also performed. To enable us to compare the magnitude of the regression coefficients, the independent variables were normalised by subtracting the mean and dividing by the variance.

Results

During and after the first year:

From Table 1a it can be seen that of all NSC results, Mathematics and Physical Science are the two most significant independent variables to discriminate between the two groups. The Pearson correlation coefficients, given in brackets, show that of all NSC results, Mathematics has the highest correlation. However, the Mathematics I predicate score, determined during the first *four months* of study, has a significantly higher correlation with the percentage subjects passed at the end of the *first year*. Stepwise linear regression shows that the coefficient for the Mathematics I predicate is almost 73 times larger than the coefficient for NSC Physical Science, even though their significance values are both smaller than 0.0001. The standard errors are given in italics. The fraction of variability in the response fitted by the model is 42%. This fraction, expressed as a percentage in the context of a regression task, represents the percentage of variance of the dependent variable that can be explained by the independent variables. Expressed as a fraction (0.41 in this case) it can be interpreted as a coefficient giving an indication of the correlation between the dependent variable and the linear prediction. It therefore shares all the advantages and disadvantages associated with correlation coefficients.

What is slightly peculiar in Table 1a is that the final stepwise linear regression result excludes NSC Mathematics. The two most significant independent variables were NSC Mathematics and Physical Science if Mathematics I (predicate) is not considered (see Table 1b). If the Mathematics I predicate is not considered, then as shown in Table 1b, the NSC Mathematics coefficient is slightly larger than the coefficient for Physical Science. None of the other NSC variables are included in the final results of the stepwise linear regression. Although the fraction of variability in the response fitted by the model is only 15%, if we calculate the correlation between NSC Mathematics and Mathematics I then we obtain a correlation coefficient of 0.44 with $p < 0.0001$, indicating a highly significant correlation.

Table 1a: ***Significance of NSC Mathematics and Mathematics I (predicate) in predicting success after*** *two semesters* ***(2009 and 2010 sample)***

Independent variables Two sided t-test/ Wilcoxon rank sum		***Significance (p-value: *< 0.1, ** < 0.05, *** < 0.01, **** < 0.001)***			
		Pearson Correlation	***Bi-variate Logistic Regression***	***Stepwise Linear Regression***	
NSC Results	Mathematics	****	**** (0.38)	****	
	Physical Science	****	**** (0.31)	****	**** (4.34)[1] *1.20*[2]
	English	*	** (0.14)	**	
	APS (aggregate of NSC subjects)	**	***(0.16)	***	
Mathematics I (predicate)		****	**** **(0.69)**	****	**** **(311.99)**[1] ***22.67***[2]

[1]Fitted linear regression coefficient [2]Standard Error

Table 1b: Stepwise linear regression on NSC results (2009 and 2010 sample)

NSC Results	Mathematics	**** (7.02)[1] *1.65*[2]
	Physical Science	**** (5.65)[1] *1.66*[2]
	English	
	APS (aggregate of NSC subjects)	

[1]***Fitted linear regression coefficient*** [2]***Standard Error***

After two years

Tables 2a and 2b were obtained in a similar fashion to Tables 1a and 1b, except that the percentage of subjects passed after *two years* of study was used as the dependent variable, the Mathematics I final score replaced the predicate score as an independent variable, and only the 2009 sample was used since the students in the 2010 sample had not finished their second year at the time of writing this article. As seen in Table 2a, the correlation between Mathematics I and the percentage subjects passed after two years (four semesters) is 0.71. The fraction of variability in the response fitted by the model is 52%. The regression using only the Mathematics I score obtained during the *first semester* accurately predicted 84.3% of the students who passed more than 50% of their subjects and accurately predicted 70.3% of the students who passed less than 50% of their subjects at the end of the *two year* period. The overall weighted error rate was 21%. The results in Table 2b are comparable to those in Table 1b. It should be noted that if Mathematics I is available, neither NSC Mathematics or Physical Science are included in the final regression equation, and NSC English gains marginal prominence in the prediction of success after four semesters (the normalised coefficient for Mathematics I is 157 times larger than the one for English), possibly pointing to the role of language in higher levels of learning.

Table 2a: ***Significance of NSC Mathematics and Mathematics I (final score) in predicting success after*** *four semesters* ***(2009 sample)***

Independent variables Two sided t-test/ Wilcoxon rank sum		*Significance (p-value: *< 0.1, ** < 0.05, *** < 0.01, **** < 0.001)*			
		Pearson Correlation	*Bi-variate Logistic Regression*	*Stepwise Linear Regression*	
NSC Results	Mathematics	****	**** (0.30)	****	
	Physical Science	****	**** (0.33)	****	
	English		** (0.11)		*** (2.58)[1] 0.90[2]
	APS (aggregate of NSC subjects)		** (0.09)		
Mathematics I (final score)		****	**** (0.71)	****	**** (404.9)[1] 18.25[2]

[1]Fitted linear regression coefficient [2]Standard Error

Table 2b: Stepwise linear regression on NSC Results (2009 sample)

NSC Results	Mathematics	*** (5.9)[1] 2.06[2]
	Physical Science	**** (7.19)[1] 1.55[2]
	English	
	APS (aggregate of NSC subjects)	

[1]Fitted linear regression coefficient [2]Standard Error

After two years Figure 1 was constructed to further explore the strong correlation between the Mathematics I result and the percentage of subjects passed after two years, depicted in Table 2a (S1-S4 refers to the period from semester 1 to semester

4). The total number of students whose Mathematics I scores fall within a 5% interval and the number of students in the same interval who completed more than 50% of the total number of prescribed subjects during the first two years (four semesters), were calculated. The percentage of students in an interval who passed more than 50% of their subjects is indicated by the small round circles. The solid line is a logistic curve fitted to the result. The fascinating result is that the *average* number of students in a specific interval who will pass more than 50% of their prescribed subjects after two years can be fairly accurately predicted using *only* the Mathematics I score obtained before the start of the second semester. From Figure 1 it is clear that more than 80% of students who obtained more than 70% for Mathematics I will *on average* pass more than 50% of their subjects during the first two years of study.

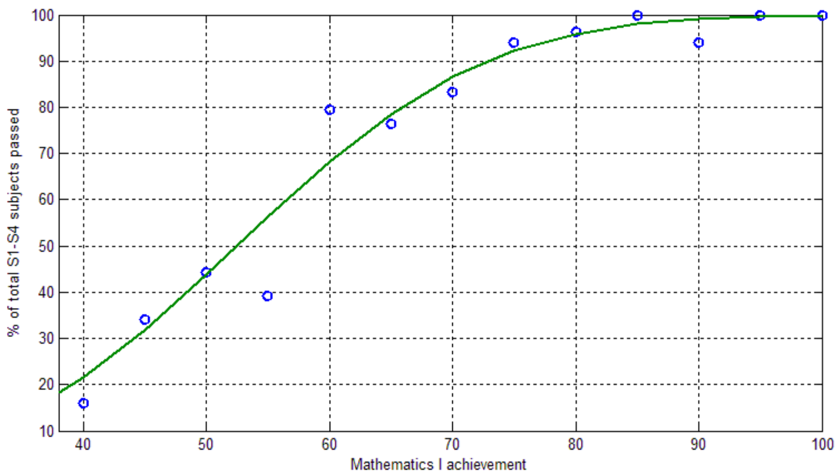

Figure 1: Logistic regression on percentage S1 to S4 subjects passed and Mathematics I

Discussion

From the results it is clear that of all NSC results, Mathematics, Physical Science, and to a lesser extent English and total APS, are all reliable predictors for success in engineering programmes at UoTs. It comes as a surprise that NSC Mathematics and Physical Science have significance values less than 0.0001 (two-sided *t-test*, bi-variate logistic regression and linear regression, see Table 2), considering the criticisms levelled at the outcomes based syllabus and the South African schooling system in general (Klopper 2009; Rademeyer 2009). As previously pointed out, the general conclusion reached in the literature is that NSC results are not a good predictor for academic success (Van Eeden, De Beer & Coetzee, 2001; Grussendorff, Liebenberg & Houston, 2004). The results in this paper have demonstrated that this conclusion is not necessarily accurate for University of Technology engineering students. What also came as a surprise was that the achievement in Mathematics I during the first semester of study has such an *exceptionally* strong predictive value. However, if one takes into consideration that on average 20 out of the 24 subjects in the National Diploma are mathematical in nature and extensively use mathematical concepts (exponents, logarithms, trigonometry, functions, matrices and vectors, differentiation and integration etc.) covered during the first semester, then there should be a strong correlation between the performance in Mathematics I and the percentage of subjects passed after the first two years of study.

The relationship between Mathematics and success is therefore worthy of deeper exploration and discussion: Figure 1 shows that there is almost a linear relationship between the average number of students passing more than 50% of the National Diploma subjects during the first two years and their performance in Mathematics I. The logistic curve flattens out for scores higher than 70%, with the result that students who obtained 70% or more for Mathematics I on average completed more than 80% of their National Diploma subjects after two years of study. The problem is simply that there are not enough students after the first semester with a firm grasp of the mathematical concepts needed for the remaining three semesters. When separating the 2009 sample into those who have passed more than 50% of the subjects after two years and those who have not, the medians for the Mathematics I score for these two groups are then 59 and 35 respectively. The two sided *t-test* confirmed that this difference is highly significant ($p < 0.0001$). As shown in Table 3, the problem is that nearly 70% of the 2009 cohort *completed* less than 60% of their subjects during the first two years.

Table 3: ***Cumulative percentage of applicants who passed all S1-S4 subjects (2009 sample***

% S1-S4 Subjects Passed	*Cumulative % Applicants*
< 50%	42%
< 60%	69%
< 70%	85%
< 80%	95%
< 100%	100%

Table 4: ***Cumulative mathematics profile of applicants (2009 & 2010 sample)***

NSC Mathematics Score	*Cumulative % Applicants*
< 50%	11%
< 60%	35%
< 70%	63%
< 80%	88%
< 100%	100%

When separating the 2009 sample into those who have passed more than 50% of the subjects after two years and those who have not, the medians of the NSC Mathematics scores for these two groups are then 4 (i.e. 50-59%) and 5 (i.e. 60-69%)

respectively. The two sided *t-test* confirmed that this difference is highly significant (*$p < 0.0001$)*. As indicated in Table 4, the problem is that 35% of the 2009 and 2010 cohorts had a score below 60% and according to Figure 1 and Tables 2 and 3, it is mainly these students who constitute the 42% who passed less than 50% of the subjects during two years.

To end our discussion on the relationship between Mathematics and success it is worth noting that if only 4% of the 592 000 learners passed NSC Mathematics with more than 50% in 2008 (Rademeyer, 2009; Klopper, 2009), consequently one of the factors that this study has identified is that the national examination *is* a useful filter and that NSC Mathematics is a sound indicator of the presence of the necessary mathematical foundation for tertiary engineering education at a University of Technology. The challenge is that there are not enough students with good NSC results entering the UoT system.

Conclusion

The results demonstrate that academic performance during the first two years of study for the National Diploma in engineering disciplines is significantly influenced by the mathematics foundation laid before entering tertiary education. It also became clear that performance during the first semester in Mathematics is a significant determinant of academic success for National Diploma students in engineering disciplines. This paper shows that pre- and post-admission mathematics achievement has the potential to be part of an early warning system to identify at-risk students in engineering programmes, that Mathematics I should be considered as a critical intervention point for UoT engineering students, and that strong support from the onset to strengthen mathematical skills could prove highly beneficial.

In our opinion the results obtained have three important implications: 1) Both the NSC-Mathematics and the Mathematics I scores could be used as powerful indicators to identify at-risk students and could be incorporated in an early warning system for potential dropouts. Obviously, such a system could include other factors such as communication skills, non-cognitive aspects, quality of accommodation, distance from campus, family and socioeconomic situation, as well as overall academic performance (Li, Swaminathan & Tang, 2009). 2) In this study only 9% of students passed all (on average 24) of their National Diploma subjects in the minimum period. Just fewer than 40% of students in the sample passed less than 50% of their National Diploma subjects after two years, and about 12% dropped out or were excluded. Seen in the light of the national study by Scott, Yeld and Hendry (2007:25) South African UoTs have to face the post facto information that nearly 50% of the students we admit to our engineering programmes are at risk right from the start. Since the admission of these at-risk students is driven by the national emphasis on access as well as by institutional financial viability reasons, our support structures and foundation programmes should be strengthened. 3) When students who performed marginally in NSC have been given a chance at studying towards a diploma in engineering but after one or two semesters it becomes clear that engineering is not the best option for them, student-friendly mobility mechanisms to enter other programmes need to be investigated.

This paper indicates that pre- and post-admission mathematics achievement has the potential to be part of an *early warning system* to identify at risk students in engineering programmes. Future research in the faculty will pay attention to the first year experience of students (Van Zyl; 2010), ways to strengthen students' mathematical pre-knowledge (Mustoe, s.a.) and external, internal and demographic factors that play a role in poor progress (Li, Swaminathan & Tang, 2009). Study skills, locus of control, motivation and attitude as discussed by others (Hendrich & Schepers, 2004; Eiselen & Geyser, 2003; De Beer, 2006) are all areas that need further investigation. It is clear that institutions need to provide additional support to a group of students which is increasing in size and in need.

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