The impact of NSC mathematics on student performance in mathematics in first-year engineering programmes: Where does the gap lie?

B.I. Collier-Reed[†], N. Wolmarans[††] and R. Smit[†††]

† Centre for Research in Engineering Education & Department of Mechanical Engineering, University of Cape Town, 7700, South Africa, email: brandon.collier-reed@uct.ac.za

†† Centre for Research in Engineering Education & Department of Civil Engineering, University of Cape Town, 7700, South Africa, email: nicky.wolmarans@uct.ac.za

†††Centre for Research in Engineering Education & Department of Electrical Engineering, University of Cape Town, 7700, South Africa, email: renee.smit@uct.ac.za

In this article we analyse the mid-year Mathematics I results for students in the University of Cape Town's engineering programmes over the period 2005 to 2009. These results are furthermore compared to the 2010 final results from a semesterised version of the course. The particular focus in the analysis is on the disaggregated group of students who wrote the 2008 NSC examinations in comparison with other groups. Concerns were raised after the 2008 NSC mathematics results showed a marked increase in success over previous years. Scepticism about the NSC mathematics results and the related increase in intake of first-year students has lead to speculation about the reasons for particularly poor mid-year Mathematics I results in 2009. This study draws on data from the mid-year Mathematics I results for the years 2005, 2007 and 2009, and the final results for the semesterised version of the course in 2010. The results suggest that the 2008 South African matriculants who moved directly from school to university showed a marked decline in success in first-year mathematics. However, the 2007 first-year mathematics results suggest that this decline cannot solely be attributed to the new NSC but rather has been taking place steadily over quite some time. We argue that the nature of first-year mathematics courses need to be redefined, in terms of content as well as how the learning environment is structured, to ensure maximum chance of success of students in the course.

Introduction

Engineering programmes are considered cognitively demanding and require at least two years of university mathematics. Selection into these programmes is based on one's marks achieved in the final school leaving examinations – the National Senior Certificate (NSC). Concerns were raised after the 2008 NSC mathematics results showed that an increased number of students across the country achieved more than 80 percent in the final mathematics examination – a situation repeated in 2009. A panel of experts who investigated the matter found that the 2008 NSC mathematics examination did not discriminate sufficiently between candidates, particularly amongst high achievers (Department of Education, 2009). This resulted in a disproportionate number of students achieving the highest mathematics symbols – and consequently, significantly more students meeting minimum entrance requirements and being accepted into engineering programmes. As a consequence, there was a 30% increase in students entering the Faculty of Engineering and the Built Environment at the University of Cape Town in 2009. A similar pattern unfolded at other universities in South Africa.

In 2009, the mid-year Mathematics I results were disappointing throughout the country. This, together with evidence from the National Benchmark Tests (NBT) Project[1], may on the

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[1] One of the objectives of the NBT is to "assess the relationship between higher education entry level requirements and school-level exit outcomes" (NBT, 2009, p.1). This report shows that only 7% of the

surface suggest that many students from the new outcomes-based school system are underprepared for success in Higher Education. Given the very different landscape that the NSC has introduced, it has become important to understand the role that school mathematics may have in contributing to the poor mid-year Mathematics I results – only 24% of a class of 666 achieved more than 50% in mid-year 2009. In 2010, the full year Mathematics I course was semesterised, with the same material being covered in each semester as in the past, but with a final exam for the first semester's work in June. The results for this semesterised version in 2010, although significantly improved, were still an unacceptably high failure rate of 53% out of a class of almost 700 – clearly a situation that demands better understanding.

The difficulty faced by first-year engineering students in a Mathematics I course is not unique to the South African context and a similar pattern has emerged in, amongst others, the United States. Reyes *et al.* (1998) suggest that it is "well known that many ... engineering freshmen do not do well in their initial mathematics class" (p.507). In fact, in California, more than half the students entering the university system are said to be unprepared for first-year mathematics (Weiss, 1997) and countrywide, more than 40% of students fail their first-year mathematics course (Wieschenberg, 1994). Exit interviews conducted at Purdue University have revealed that a significant reason for the large drop-out rate amongst first year engineering students includes difficulty with their first mathematics course (Budny, LeBold, & Bjedov, 1997). Klingbeil *et al.* (2004) argue that "the correlation between retention rates and the inability of incoming students to progress through the required calculus sequence cannot be ignored" (p.12170) and that there is a need to redefine the way in which first-year mathematics courses are taught with the "goal of increasing student retention, motivation and success in engineering" (p.12169).

Although these international issues are arguably similar in the South African context, much of the discussion surrounding the poor Mathematics I mid-year results has focussed almost exclusively on the fact that the 2009 student intake was the first product of a new school curriculum and teaching philosophy (Outcomes Based Education). The view expressed by many was that the situation in South Africa with regard to mathematics was more pronounced than elsewhere. They suggest that learners had been poorly prepared at school and had completed a mathematics curriculum that was nominally similar to that of the discontinued Standard Grade mathematics. In support of this anecdotal position, Serrao (2009) has suggested that the weaknesses in the school mathematics 2008 examination was directly responsible for the poor performance of students in university-level Mathematics I courses.

The question thus emerges as to how critical the role of inflated/undiscriminating school mathematics results are in understanding the ongoing disappointing mid-year Mathematics I course results. Too often the "new" FET mathematics is presented as the *cause* of these results. This article looks to critically evaluate the nature of student success in the first-year Mathematics I course at the University of Cape Town by considering results over a five year period up to 2009. These results are then looked at in the context of the 2010 results for a semesterised version of the course – where the same material is covered, but with the work subject to a final examination in June.

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engineering students at UCT achieved at the 'Proficient' level (deemed not to require additional assistance to perform at the degree level). 73% of the engineering students performed in the 'Intermediate' category and those at the bottom end of this category are expected to require additional support in the form of augmented programmes, extra tutorial help, etc. A significant 20% of the engineering students were found to have only 'Basic' mathematical skills and would likely need to be placed in an extended programme.

Constituting the class

This study draws its empirical data from the mid-year results for the first-year Mathematics I course taken by mainstream engineering students at the University of Cape Town. Four sets of data have been drawn on: the mid-year results for 2005, 2007 and 2009, and the final results for the semesterised version of the course in 2010. The data are interrogated in the context of the following questions:

- Do the results reveal anything about the stability of the course under review?

- Do the results support the anecdotal view that student success in this course has declined markedly since the introduction of the NSC?

For 2005, the data consist of the averaged mark for a class test and a test written during the June examination session, while for 2007 and 2009, there were three class tests (one of which was written during the June examination session) which were averaged. For 2010, the final mark for the semesterised version of the course is used. In the analysis, students in each year are grouped into the following categories (students on the extended programme were not included in the data as they participate in an alternative mathematics course):

- *Matric:* Students who wrote the South African matriculation examinations and then proceeded directly to first year at university;
- *Matric+Gap:* Students who wrote the South African matriculation examinations and then either took a break from their studies or studied elsewhere before entering their first year at university;
- *International (Int):* Students who completed an international school leaving examination, often, but not exclusively, the A-level examination. They have either entered university directly or after a break from their studies; and
- *Repeat:* Students repeating the course having failed it previously. Data for students repeating the course in 2007 is unavailable.
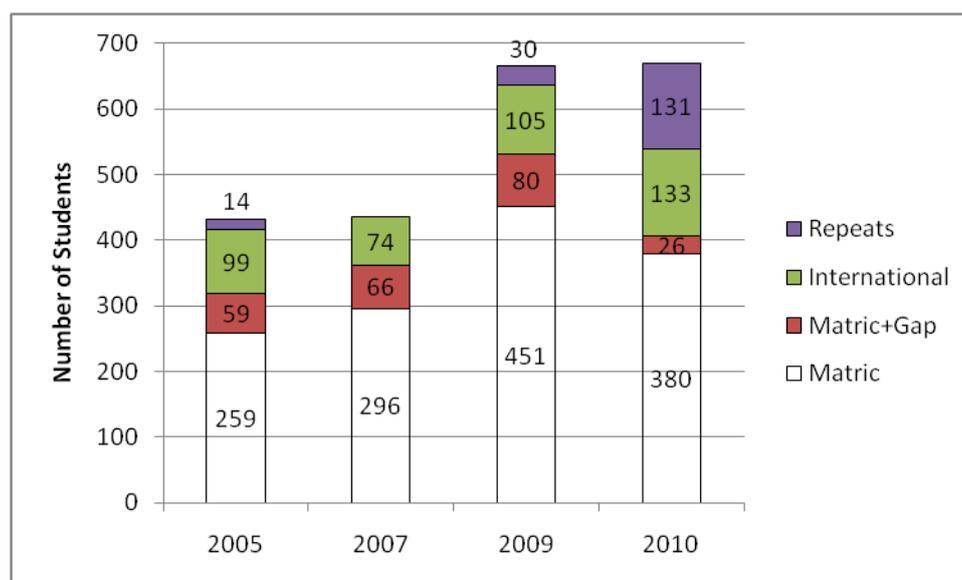

Figure 1: Distribution of groups in Mathematics I

In Figure 1, the size of the Mathematics I class for each of the groups under consideration is illustrated for each of the years under review. It is immediately apparent how prior to the

NSC, class sizes were in the region of 430, whereas in 2009 this increased markedly to 666 – primarily due to the increase in the *Matric* group. The class size in 2010 is similar at around 670, but 131 of these are repeats – an increase of more than 400%.

In 2005 and 2007 the *Matric* group completed the old Senior Certificate examinations in their Grade 12 year – and a *Gap* year meant exactly that: entering university one or more years after having matriculated. In 2009 and 2010, the Matric group are those in the class who completed the NSC examination while the *Matric+Gap* students are those who completed the old Senior Certificate examinations. It is for this reason that this group has reduced to only 26 in 2010.

Considering the stability of Mathematics I over time

It will only be possible to make claims about what is happening in the Mathematics I if it can be shown that the course has remained stable over the five-year period under review. To this end, we have extracted the results of those students who did not write a South African matriculation examination, but rather an international examination, in many cases A-levels. We have chosen this group as a nominal "control group" and have made the assumption that their level and type of preparation should not have changed significantly over this period as their curricula are mature.

Our argument is that if the course results of the international examination students in Mathematics I are statistically comparable over time then the course *itself* should not have changed to any significant degree. To test this proposition, a t-test was performed on pairs of data to determine whether or not the groups are in fact comparable. At the 95% confidence level, for data with a large number of degrees of freedom, a t-statistic below 1.645 indicates that there is no statistical difference between the data sets. The statistical analysis including the results of the t-tests for the international examination student groups are shown in Table 1. The results from 2010 have not been included in this analysis as the dynamics of writing a final examination in June changes the parameters of the experience significantly. Furthermore, as it is a final examination, only students obtaining a "duly performed" certificate (or DP) may sit for the examination – and in this case almost 25% of the class did *not* obtain enough credit during the semester and could thus not participate in the examination. These "exclusions" from the process would make comparison particularly problematic.

Table 1: Results for students with international school leaving examinations

	2005	**2007**	**2009**
Sample size	99	74	105
Number of passes	33	30	43
Pass rate (%)	33	41	41
Mean (%)	44	45	46
Standard deviation (%)	17	17	18
t-test$_{0.05}$ with 2009	0.744	0.497	
t-test$_{0.05}$ with 2007	1.071		

The data suggest that there is no significant difference between the years, and therefore we would claim that the courses have not changed significantly in terms of assessment practice. The mean and standard deviation of the groups are comparable and the stability of the coefficient of variation further suggests that the students from the international examination

groups are stable over time. Consequently we conclude that the results for the Mathematics I course can be compared over time. We would thus suggest that a change in the performance of other groups in the Mathematics I course is more likely a result of a change in their prior schooling than a change in the course itself.

Comparison of the course results between groups

In order to explore the anecdotal view that the new school curriculum has resulted in a declining success rate at university in mathematics, the mid-year course results have been analysed in terms of the four groups of students identified above. Only the results of the total group, the disaggregated *Matric* group, and the I*nternational* group (*Int*) are presented in Table 2. For reasons similar to those presented earlier, the 2010 results are not included in this table. Furthermore, it should be noted that only the 2009 *Matric* group (those who wrote their final matriculation examinations in 2008) have completed the full OBE curriculum.

Table 2: Mathematics I mid-year results

	2005			**2007**			**2009**		
	Total	**Matric**	**Int**	**Total**	**Matric**	**Int**	**Total**	**Matric**	**Int**
Sample size	431	259	99	436	296	74	666	451	105
No. of passes	162	103	33	110	70	30	162	81	43
Pass rate (%)	39	40	33	26	24	41	24	18	41
Mean (%)	46	47	44	39	38	45	39	36	46
Standard deviation (%)	16	17	17	18	18	17	17	16	18

Although in absolute numbers the size of the different groups has varied somewhat over time, the pass rates of the three groups presented in Table 2 paint an interesting picture. The pass rate for the *International* students has increased in a narrow range from 33% to 41% with a corresponding mean mark that has remained remarkably stable (but increasing) from 44% to 46%. The pass rate for the *Matric* group has declined steadily from 40% in 2005, to 24% in 2007, and finally to 18% in 2009. The mean mark during this time has also dropped from 47% to 36%. The consistent standard deviation reflected in each of the groups in turn suggests that a comparison of this nature is justified. These data are illustrated in Figure 3.
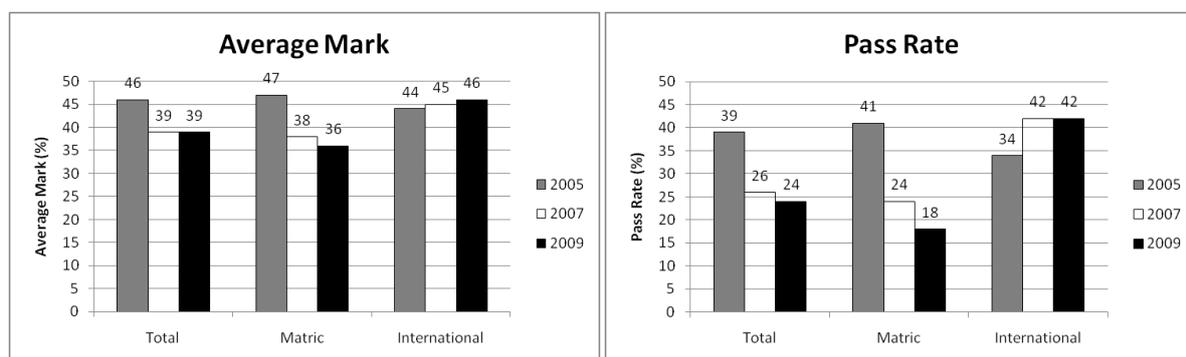

Figure 3: Average Mark and Pass Rate for Mathematics I

We would argue that since we have shown through the use of a control group (the *International* students) that the course has not changed significantly, the marked decline in both the average and the pass rate of the *Matric* group is of concern. However, the ongoing systematic decline in results from 2005 would suggest that this trend cannot be solely blamed

on the 2008 NSC examinations and OBE curriculum alone – it may have started as early as 2005.

The nature of the Mathematics I results

In order to further consider whether the anecdotal view that student success in Mathematics I has declined markedly since the introduction of the NSC is justified, we turn now to look at how students in the *Matric* and *International* groups have performed in the course over the period under review. Figure 4 illustrates, in absolute numbers, the distribution of mid-year results for Mathematics I.
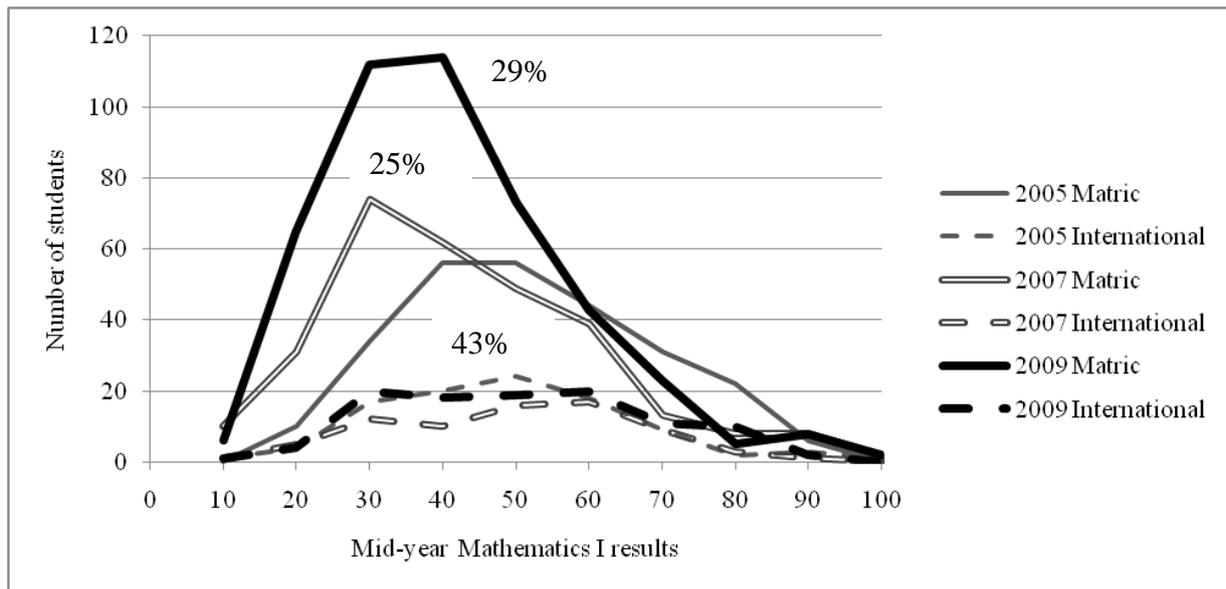

Figure 4: Distribution of mid-year results in Mathematics I

It is immediately apparent how similar the distribution of the results is for the International students in the course. This further supports our claim that the course itself has not changed significantly during the period under review. However, one can't help but being struck by the data presented by the *Matric* students. As these are absolute numbers – and class sizes have grown – one would not expect to see the data overlap in any significant way. What is important to note though is how the mode[2] of the data has shifted from 43% in 2005 to 25% in 2007 – but increased again in 2009 to 29%.

An alternative presentation of the same data is shown in Figure 5. Here cumulative levels of success are shown for the *Matric* group during the period under review. Consider the 50% level for the cumulative results presented. In 2005, 106 students were achieving at least a pass in Mathematics I at mid-year. In 2009 – even with an increase of 174% in the number of students in the *Matric* group – 24% *fewer* students were passing. This would tend to support the view that the NSC was a significant cause of students not being able to perform at the level required of a first-year mathematics course. However, when one looks at the 2007 results, one notices that in absolute terms there were 12% fewer students who had managed to achieve at least 50% for the course by mid-year than in 2009 – the first year of the NSC students entering UCT.

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[2] Mode is a statistical term for the result that occurs most often in a sample.
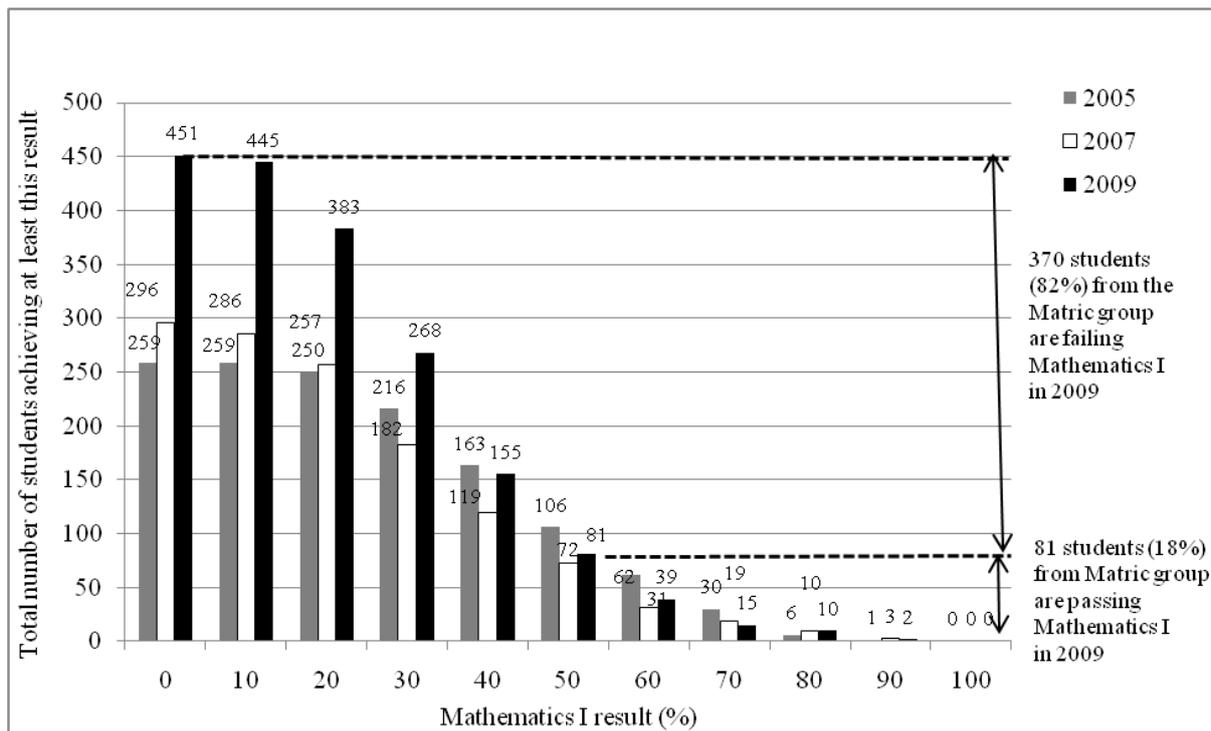
Figure 5: Cumulative distribution of mid-year results in Mathematics I for the Matric group

Introducing the 2010 semesterised Mathematics course data

During the first semester of 2009, the numbers of students who were significantly underperforming in Mathematics I was a cause of concern in the EBE faculty. A strategy was introduced whereby students could opt to deregister from the full-year Mathematics I course and essentially repeat the first semester's work in the second semester. This ultimately led to the full semesterisation of this course with both halves being presented in each semester. It is problematic to directly compare final results from a terminating semester course in 2010 with that of mid-term results from a whole-year course. However, the results do help to inform the ongoing discussion around this issue.

Table 3: Analysis of the 2010 semesterised Mathematics course

	Matric	**Matric+Gap**	**International**	**Repeat**
Full class size	380	26	133	131
No DP certificate	115 (30%)	6 (23%)	27 (20%)	11 (8%)
Sample size	265	20	106	120
No of passes	140	15	79	91
Pass rate (%)	53	75	75	76
Mean (%)	47	57	55	54
Standard deviation (%)	18	19	17	15

Table 3 presents a descriptive statistical analysis of the semesterised mathematics course for each group. In this table, the data does not use the full class size for each group as a significant portion of the class did not achieve a "duly performed" certificate (or DP) and were thus not eligible to sit for the examination. In previous years, each student had a mark at mid-year – even if there was no realistic way that they could pass the full course at the end of the year. However, the argument has been made that Mathematics I, being a whole-year

course, gave students the opportunity to "up their game" and potentially pass at the end of the year even if they had been performing poorly during the year.

Table 4 shows the descriptive statistics of the mid-year results of the Mathematics I courses as well as the 2010 semesterised version – the 2010 course results "conveniently" stripped of students with – in the view of the course convenor – no realistic chance of success. We have argued that the material presented in the Mathematics I course – as well as the associated assessment criteria – have remained consistent over the five years under review. Given that the semesterised version of the course is the same material covered in the first semester of the Mathematics I course, it would be interesting to consider if the *International* students continue to perform at the level consistent with the previous five years. Table 4 indicates that the pass rate for the *International* group in 2010 is 75% – compared with 33%, 41%, and 41% for 2005, 2007, and 2009 respectively. Even if the 27 students who were excluded (no DP) from writing the examination are included as failures, the pass rate would still be 59% or an improvement of more that 50% on prior years.

Table 4: Descriptive statistics of selected mathematics results

	2005		2007		2009		2010	
	Matric	**Int**	**Matric**	**Int**	**Matric**	**Int**	**Matric**	**Int**
Pass rate (%)	40	33	24	41	18	41	54	75
Mean (%)	47	44	38	45	36	46	47	55
St dev (%)	17	17	18	17	16	18	18	17

It may be less than fair to suggest that the course management has compromised the assessment strategy of the course to improve on the abysmal 18% pass rate of the *Matric* group in 2009 as no doubt they would have carefully considered how they could improve on the teaching and learning approach adopted in the class for the 2010 academic year. However, the fact remains that the pass rate for the *Matric* group has improved from 18% in 2009 to 53% in 2010 – a remarkable improvement of 300% (or 200% if those without DPs are included as failures). This improvement – when seen in the context of a significant increase in the *International* group – suggests that the consistency of the course itself has changed.

Discussion and concluding remarks

By focusing on the *International* group in the class, we have shown in this article how the Mathematics I course has remained consistent in terms of assessment strategy for the years 2005 to 2009 – the period under review – and that the results obtained during these years are directly comparable. The data clearly confirm a general decline in the performance of students during this period. Emerging from the analysis of the results is a clear indication however that the success of the *Matric* group has declined markedly during this time. Contrary to the perception that this has primarily been precipitated by the move to the new OBE system implemented in schools and the associated NSC examinations, we have shown how the results achieved by the *Matric* group in the Mathematics I course in 2007 are in fact *worse* than those in achieved by that group in 2009. Hence we conclude that the poor performance of the first-year students since the introduction of the NSC is not a sudden or dramatic shift, but rather part of a gradual deterioration in the preparedness of these students. It is our view that simply changing the Grade 12 NSC mathematics examination is unlikely to produce, or even identify better prepared students.

In the light of these findings, any discussion that simply focuses on scepticism regarding the NSC mathematics results is likely to be a red herring: it distracts from the potentially much more serious issues of mathematics teaching and learning at school level, as well as the assumptions made by higher education institutions about the mathematical skills of incoming students. Universities have limited influence over what happens in secondary schools, and any significant change there will take time. The fact remains that our first-year students are the "cream of the crop". Recent calculations based on the 2005 HEMIS[3] data indicate that the gross participation rates in higher education in South Africa are as low as 16% in the 20-24 year old age group (Scott et al, 2007). The "pool" from which suitable science and engineering candidates are selected is even smaller: 20% of the 2008 National Senior Certificate (NSC) candidates achieved a pass that allowed them access to admission to degree studies at higher education institutions, and only 7.9% of the candidates achieved more than 60% in the 2008 NSC mathematics examination – a requirement to enter engineering programmes (Department of Education, 2008).

It is clear then that we cannot simply accept these poor success rates of our first-year students in courses such as mathematics; nor can we adopt the position that schools must better prepare students as we are selecting for entry into our programmes from the top 5% of the students successfully completing Grade 12. We must take ownership of the issue beyond – as the results for the 2010 semesterised Mathematics course suggests – simply manipulating the final pass rates to satisfy the need for students to progress in their studies. The reality that we face is that we have an ever increasing "tail" in our mathematics class: 240 students failed the first semester mathematics course in 2010 – 63%! The Department of Education has invested significant funding into increasing the throughput of engineering programmes, but forging ahead by setting up 63% of a mathematics class to fail must run counter to any effort to improve this situation.

We also need to recognise that our situation in South Africa is not unique. In the introduction we argued that in some cases as much as half of students entering first-year mathematics in some states in the United States are unprepared for their studies – with more than 40% failing nationwide. It was suggested that throughput rates are directly adversely affected by this situation as students tend to drop out after performing poorly in these fundamental courses. These comments should be seen in light of the fact that in many colleges and universities there are specific "pre-calculus" courses to help address the fact that schools do not adequately prepare students for what is expected of them when they enter first-year mathematics – a model currently under discussion in our Faculty. This notwithstanding, there is a general view that the nature of first-year mathematics courses need to be redefined, in terms of content as well as how the learning environment is structured, to ensure maximum chance of success of students in the course.

An unfortunate response by administrators that has eclipsed much of the pedagogic discussion that should be taking place is the nominally pragmatic view that the best way to address the problem is simply to raise entrance requirements. In our previous work (Wolmarans, et al. 2010) we have argued that when looking at the 2009 *Matric* group results for Mathematics I, the large degree of scatter in the correlation between the results and the entry requirements leads one to believe that simply raising entry requirements would not address the problem. There are 240 students who failed the 2010 mathematics course with *many* of these students in the top quartile of entry points achieved. Consequently, a more nuanced position to admission needs to be adopted. The NBT has been shown to provide

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[3] HEMIS is the Higher Education Management and Information System

useful information that could be used to augment the school-leaving results and the argument could be made that the NBT scores should play a more dominant role in ensuring that students admitted to our programmes have at least a reasonable chance of success.

The large number of unsuccessful students in both 2009 and 2010 casts a shadow over the notion of broadening access to higher educational institutions. Granting students access to our programmes without some reasonable chance for success can only be seen as disingenuous. Furthermore, the view that the first year should serve as a 'filter' to 'weed out' unsuitable students who should not be in higher education in the first instance, is problematic. Higher education institutions have to grapple with ways to find educational strategies that would impact student success (Scott et al, 2007). If higher education institutions are to remain relevant, that is, if we are serious about increasing access to higher education in an attempt to alleviate the critical shortage of science and engineering graduates in South Africa, we have to find ways to respond adequately to the problem of assisting under-prepared first-year students "bridge the gap" and succeed in their studies.

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