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The transition from high school mathematics to engineering mathematics.

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Abstract

Mathematics is an essential course in the study of engineering. It can be argued that mathematics is the backbone of engineering. It is important for educators to have an understanding of the varying backgrounds of students and the way in which this affects their learning. This information will have an impact on teaching methods in the classroom which will ensure that they are inclusive and not exclusive. This is especially true in South Africa where we have a range of schools with different standards even though the final examination is the same. There seems to be a gap that exists between high school and first year engineering mathematics programs. First year engineering mathematics programs seem to present school learners joining the program with significant problems. This article attempted to identify whether there is a mathematics knowledge gap in South Africa. What the impact of this gap on engineering students was and who was responsible to address this problem. This study evaluated the differences between matric mathematics and university engineering mathematics 1. BTech and first year students interviewed and their opinion solicited with regard to the existence of a knowledge gap between matric mathematics and engineering mathematics 1. The pass rate for engineering mathematics 1 was compared over the past four years (2014 to 2017) to determine influence of CAPS on the engineering mathematics 1 results.

Keywords: Mathematics Knowledge gap; engineering education.

1. Introduction

Mathematics is a vital course in the engineering curriculum and is critical to the education of engineering students irrespective of their field of study. Many aspects of engineering activity require formulating a problem correctly and finding an adequate method to solve the problem [1].

Internationally mathematics standards used to enable smooth transition for school learners to the tertiary education environment. It can no longer be assumed that school learners are adequately prepared for tertiary education [2]. It is important for educators to have an understanding of the varying backgrounds of students and the way in which this affects their learning. This information will have an impact on teaching methods in the classroom which will ensure that they are inclusive and not exclusive. This is especially true in South Africa where we have a range of schools with different standards even though the final matriculation examination is the same.

First year engineering mathematics programs seem to present school learners joining the program with significant problems [3]. It would appear that for some students there is a gap between school mathematics and the knowledge required to cope successfully with the first year tertiary mathematics program. It is essential to address this problem as it can be argued that mathematics is the backbone of engineering

2. Objective

In this paper the existence of a mathematics knowledge gap in South Africa as well as the impact on first year engineering students will be explored. The question of who is responsible to address this gap will be discussed.

3. Literature Review

It has been established that a proficiency in mathematics prior to embarking on a tertiary education program in engineering is more important to students than in most other fields of study [4].

In the report on the National Benchmark Tests Project (NBTP) 2009, it was found that only 7% of engineering students were proficient in mathematics. Of the engineering students entering the program 20% had a basic understanding of mathematics and these students would need to be in an extended programme or acquire additional assistance in mathematics [3]. In 2011 the “Curriculum and Assessment Policy Statement” (CAPS) was introduced and outcomes based education amended. The Department of Basic Education indicated that CAPS was not a new curriculum but an amendment to the National Curriculum Statement (NCS). Planned implementation of CAPS in the senior phase was in 2014 [4]. There have been reports in popular media that high school mathematics has improved since 2014 [5] but scientific evidence is lacking.

Improving access to tertiary institutions is the aim of many international high school curricula but the question has been asked whether the accessibility is negatively affecting students’ ability to succeed in tertiary education [7].

Statistical analysis was done of the engineering mathematics 1 results of 2005, 2007 and 2009. These results were of first year engineering students at the University of Cape Town. International students’ results were used as a control group because their results for engineering mathematics 1 remained basically the same over this time (2005,2007 and 2009). The assumption was made that as the results from the international students had remained the same the course presentation and content were the same. The results showed that there has been a gradual decline in performance of students in the first year engineering mathematics 1. This decline was apparent even before 2009 when the NSC was used [3].

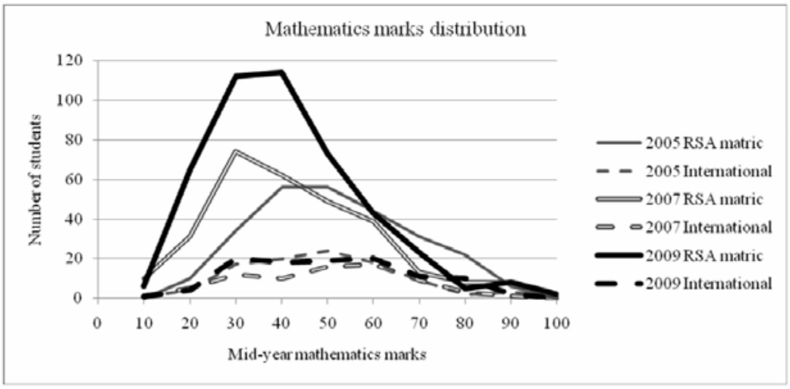

Fig. 1 Distribution of mid-year results for mathematics [3]

At an international level it has been established that students find the transition from high school mathematics to engineering mathematics difficult. Many first year students lack appropriate mathematical thinking in a number of situations [4]. In the UK this has been a concern since the 1960's [5]. The problem is not a new problem and it is not unique to South Africa. It is difficult for students to make up for poor high school mathematics at university level [4]. A correlation was found between positive experience in high school with mathematics and a student's performance in university mathematics courses. Some students with negative high school experiences never fully recover [4]. The situation in South Africa in respect to mathematics is more pronounced than elsewhere. It is concluded that South Africa is still failing to meet expectations in mathematics instruction [6].

3.1. Factors affecting mathematics education

Mathematics education begins in language and often problems occur because of language [7]. Asian students tend to perform better at mathematics compared to non-Asian students. Research has indicated that one of the contributing factors in this difference lies in the words used for numbers as well as mathematical terms. In Chinese these are transparent and relatively simple when compared to Western Languages [8]. In most of the African languages the words and mathematical terms have not been developed well [9]. As English is the dominant language, specifically also for tertiary education in South Africa, it is generally interpreted as a waste of time to develop the mathematics register. Language used for mathematics affect students mathematical abilities [9]. In South Africa there is a challenge to provide mathematics to a diverse society in a number of official languages. In research conducted, 8000 pupils in 200 schools were evaluated, English proficiency and language usage and their relationship with mathematics achievement were explored. The study revealed that pupil's proficiency in English was a strong predictor of their success in mathematics [10].

Stereotypes also had an impact on mathematics achievement. Many pupils believe that mathematics is only for "clever" pupils or those who inherited a mathematical ability [11]. In the United States of America several studies were conducted to determine whether even passing reminders that people belonging to a specific group, stereotyped to be inferior in academia, could affect results [12]. It is argued that anyone whose group is stereotyped to have a lack of ability in some domain is susceptible to threats and this could undermine their intellectual performance [13].

In one study they gave black and white students a half-hour test using difficult items from the verbal Graduate Record Exam (GRE) [14]. In the stereotype-threat condition, they told students the test identified academic ability thus potentially causing stereotypes that black students are less intelligent than white students. In the non-stereotype threat condition, researchers told students it was a problem solving task that said nothing about ability, likely translation stereotypes are irrelevant. In the stereotype-threat condition black students who were matched to white students by SAT scores, did less well than the white students. In the exact same test, but described differently in terms of problem solving abilities, the performance of black students rose to match that of equally skilled white students as was expected.

In a similar study it was found that by telling women that a mathematics test did not show gender differences improved their test performance when compared to telling them that the test did show gender differences [15]. In both cases academically top performing, strong, motivated students were used in the experiments. The same was found with Latino students [16] as well as elderly individuals. Elderly individuals primed with the stereotype of "old age and senility" performed worse than elderly individuals exposed to the more positive "old age leads to wisdom" stereotype [17].

These results also held true in majority groups where White students were exposed to the stereotyped threat that Asian students typically were better at mathematics than White students [13]. This means that part of students' performance in mathematics is determined by something outside the individual such as social influences.

Successful role models can help to overcome the effects of stereotype threats. This seems to be effective only if students perceive role models to have deserved their success [18].

3.2. Interventions to bridge this gap

Considering the above information institutions of higher education may have to find strategies that could improve students' chances of success. Improved access to South African universities is meaningless if students don't have a reasonable chance to succeed in their studies [3].

Internationally tertiary institutions have tried various interventions to assist students. In Australia school learners have the option to take a subject where first year calculus is taught and then receive credit for it in their first year at university [19]. The course did improve students' mathematics skills and it had the added benefit of improving relationships with schools. In the USA many schools, but not all, offer advanced mathematics options such as calculus. In South Africa some schools also offer advanced mathematics which better prepares students for university mathematics. However, a large number of schools offer only mathematics literacy.

A Canadian university created a mathematics review manual which consisted of a narrative part which gave information about the university and the mathematics courses the student could take as well as a brief review of background material that students would need for their university mathematics courses. This included a large number of solved problems as well as additional problems students were advised to do [4]. This was sent to students before they started university, few students actually did the work, but they brought the manual with them and referred to it during their first year of study. They found this guide beneficial. The first year course was also adjusted to include a section on mathematical language as it could not be assumed that students would be familiar with this knowledge [4].

4. Methodology

The 2018 Gauteng Province mathematics annual teaching plan was obtained from a matric high school teacher. The engineering mathematics study guide was obtained from a lecturer in engineering mathematics 1 for National Diploma students at the University of Johannesburg. These two documents were compared and evaluated to identify potential knowledge gap between school mathematics and engineering mathematics.

Three questions were designed and then these questions were put to ten first year students enrolled for the National Diploma in engineering, by a project research student [24]. The questions being

- Is it a simple transition from high school mathematics to engineering mathematics 1
- Are there academic differences between high school mathematics and engineering mathematics 1 and
- Is there a need that High School mathematics cover at least the basics of the topics in engineering mathematics 1.

The results of the questionnaire was then discussed in a group with the Bachelor of Engineering Technology (B.Tech) students under the guidance of the project research lecturer. This was in an informal setting. The aim of this discussion was to determine the B.Tech students' experience and perception of the transition from high school to engineering mathematics. The average pass rate from 2014 to 2017 was compared to identify whether there had been an improvement in pass rate of engineering mathematics 1 after CAPS was introduced.

5. Results

The two documents covering the teaching plans were compared in a table (see appendix 1). It was found that binomial series, matrices and determinants were not covered in high school. Complex numbers were not covered, no integral calculus and very basic differential calculus was covered. The matric teaching plan was considered as being very broad but lacking in depth.

Of the 10 students interviewed in their first year 6 students said the transition to engineering mathematics was simple, 9 said there was academic differences between high school mathematics and engineering mathematics 1 and 7 said there was a need to cover at least the basics of the topics in Engineering mathematics 1. In the discussion with the B.Tech students when they were asked whether there is a mathematics knowledge gap all indicated positively even if they had no difficulty with engineering mathematics 1. These student were of the opinion that the high school attended was very important and made a difference in easing the transition to university. Students with the opportunity to do advanced mathematics in high school found the transition from high school mathematics to engineering mathematics to be less difficult than their peers who had not done advanced mathematics.

A graph was drawn to compare the percentage students who started and passed engineering mathematics 1 from 2014 to 2017. The average number of National Diploma students enrolled for engineering mathematics 1 was 950. It is clear from this graph that generally students are still struggling with mathematics 1 after the introduction to CAPS. Further research may be valuable to determine why there was a significantly higher pass rate in 2015.

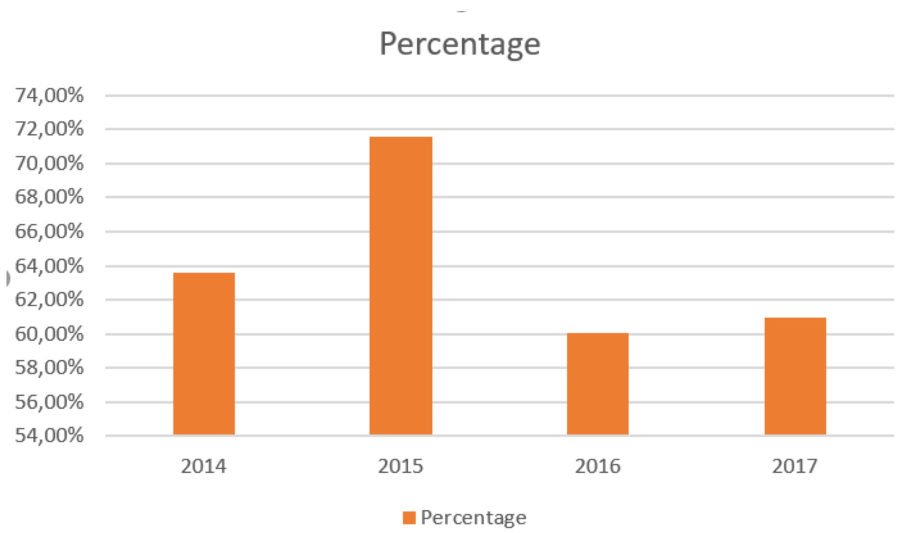

Fig 2. Percentages of students who passed mathematics 1

6. Discussion

It is not generally expected that all the components of engineering mathematics 1 should be covered in high school but the basics must be covered adequately so that the next level can be built on that foundation. Matric mathematics topics and the way they are taught currently does not make it easy for students to adjust to university mathematics [3].

From the result it appears that as in many other countries the high school curricula are broad but not deep. This poses problems specifically in mathematics as high school leads to students adopting surface learning attitudes contrary to deep learning methods which are required at the university [4]. Deep learning enables students to apply information to problems in different settings. Surface learning is scratching the surface of a study area which leads to superficial knowledge. This holds for all students.

Most of the students in the discussion group were of the opinion that there is a knowledge gap between high school mathematics and engineering mathematics 1. Students with the opportunity to do advanced mathematics in high school had less problems with engineering mathematics 1. Where possible schools should implement advanced mathematics courses. A number of South African schools offer mathematics literacy only which automatically excludes all pupils from those schools from ever studying engineering.

The first students to write the new CAPS matric were 2014 matric pupils. The average pass rate from 2014 to 2017 was compared and although there was an improvement in 2015 that improvement was not sustained. Further research is required to determine whether CAPS has led to improvement in university mathematics.

As perception students have of themselves affected their academic performance lecturers have to be aware to not create stereotype threat situation in their classrooms. The Faculty could provide lecturers with workshop to ensure that they understand stereotype threats and how easily students can be affected by it. Obtaining reading material for students about deserving role models should be relatively easy to put together in order to overcome stereotype threats.

Students need some exposure to mathematical terms in English especially if mathematics was not taught in English.

Student who fail Engineering Mathematics 1 often add a year to their studies as mathematics is a prerequisite for many subjects in the various engineering fields. Repeating a subject also leads to timetable clashes, which affect the time it takes to complete the qualification. Failing mathematics also has an impact on students' motivation.

At the University of Johannesburg repetition of engineering mathematics 1 is offered in the second semester on Saturdays to assist students who failed in the first semester.

Tertiary institutions should become involved in bridging the mathematics knowledge gap as it is necessary to improve retention.

7. Conclusion

It can be concluded that there is indeed a mathematics knowledge gap between high school and engineering mathematics. This gap results in students adding time to complete their qualification which also increases costs. It leads to students becoming demotivated to complete their engineering qualification.

Students perceptions about themselves as well as their proficiency in English influences their academic performance and understanding of mathematics.

Tertiary institutions should become involved in addressing this gap as accessibility to tertiary universities is important but it has no value if students are unable to succeed.

8. Recommendation

It is recommended to assist high school students by providing students with a bridging course which could be made available electronically before the students start university. High Schools and Universities should interact specifically with regard to the requirements of University subjects. Senior students should be used as mentors to first year students as they recently had completed the course and would be sensitive to the problems and frustrations experienced by the first year students. There should be some benefit for senior students to encourage them to fulfill this undertaking. Other potential benefits could be realized by the interaction between senior and junior students such as improving social and academic integration of first year students at the university.

Faculty should be aware of not creating stereotype threat situations and how to rather create positive environment for students to perform. There could be a need for a workshop to accomplish this awareness. Staff should attempt to expose students to deserving role models.

A lecture dealing with mathematical language may be valuable in the first year class as it cannot be assumed that students grasp these concepts. The bridging course should also include meaning of mathematical terms.

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Appendix A.

High school syllabus	**Mathematics 1 syllabus**
Number patterns and Sequences & Series Arithmetic sequence and series	**Algebra** The binomial series Matrices and determinants Functions and Relations Algebraic Graphs
Sequences & Series Sigma notation. Sum of series. Derivation and application of the formulae for the sum of arithmetic and geometric series:	**Transcendental Functions** Exponential rules, equations and graphs Logarithmic rules, equations and graphs Manipulate equations by changing the subject
Functions • Definition of a function. Focus on the following characteristics: • domain and range, • intercepts with the axes, • turning points, • minima, maxima, • asymptotes (horizontal and vertical) • shape and symmetry, • average gradient (average rate of change), • intervals on which the function increases /decreases. • General concept of the *inverse of a function* and restriction of the domain to ensure that the inverse is a function.	**Trigonometric functions** Trigonometric identities and equations The sinusoidal graph The circle and its properties
Functions: Inverses • Determine and sketch graphs of the inverses of the functions defined by $y = ax + q;\ y = ax^2$. • Graph of the function defined by $y = b^x, b > 0$ and $b \neq 1$	**Complex Numbers** The Rectangular, Polar and Exponential form of a complex number Algebraic operations performed in Rectangular, Polar and Exponential form De Moivre's Theorem The solution to complex equations Applications of complex numbers
Functions: Exponential and Logarithmic • Definition of a logarithm: LAWS NOT EXAMINABLE $y = \log_b x \Leftrightarrow x = b^y, b > 0 ; b \neq 1$ The graph of the function define by $y = \log_b x$ for both the cases $0 < b < 1$ and $b > 1$.	**Differential Calculus** Methods of differentiation Derivatives of transcendental functions Higher derivatives Applications of differentiation

Financial Maths • Solve problems using present and future value annuities • Calculate the value of *n* in the formulae $A = P(1+i)^n$ or $A = P(1-i)^n$ • Critically analyse investments and loan option(s) [including pyramid].	**Integral Calculus** Standard Integration Transforming algebraic functions Integration of transcendental functions Definite integrals Applications of Integration
Trigonometry • Compound angle identities: $\sin(\alpha \pm b) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta$ $\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\alpha\sin\beta$ • Double angle identities: $\sin 2\alpha = 2\sin\alpha\cos\alpha$ $\cos 2\alpha = \cos^2\alpha - \sin^2\alpha$ $= 2\cos^2\alpha - 1$ $= 1 - 2\sin^2\alpha$ Solve problems in two and three dimensions.	
Euclidian Geometry • Conditions for polygons to be similar. • Revise grade 10 Midpoint theorems. **PROVE:** • Proportionality **USE :** • Proportionality and Midpoint Theorems. **PROVE:** • Equiangular triangles are similar. **USE:** • Equiangular triangles are similar. • NB: Converses to be taught for application purposes **USE :COMBINED** • Proportionality and Midpoint Theorems. • Equiangular triangles are similar. • Triangles with sides in proportion are similar. Pythagorean Theorem by similar triangles	
Functions: Polynomials • Factorise third-degree polynomials. Apply the Remainder and Factor Theorems to polynomials of degree at most 3 (no proofs required)**(1 day).** • Intuitive understanding of limit concept. • Approximate instantaneous rate of change or gradient of function at a point	
Differential Calculus • Limits to define the derivative of a function	

$f'(x) = \lim_{h \to 0} \frac{f(x+h) - f(x)}{h}$ • First principles. Rules of differentiation • Cubic graphs. • Equations of tangents to graphs of functions. Second derivative and concavity. • Practical problems concerning. optimisation, rate of change and motion	
Analytical Geometry • The equation of a circle (any centre) $(x-a)^2 + (y-b)^2 = r^2$ The equation of a tangent to a circle	
Statistics • Revise symmetric and skewed data • Use statistical summaries, scatterplots, regression (in particular the least squares regression line) and correlation to analyse and make meaningful comments on the context associated with given bivariate data, including interpolation, extrapolation and discussions on skewness.	
Counting and Probability • Revise: ♦ dependent and independent events; ♦ the product rule for independent events: P(A *and B*) = *P*(*A*) × *P*(*B*) ♦ the sum rule for mutually exclusive events A and B: *P*(*A* or *B*) = *P*(*A*) + *P*(*B*) ♦ the identity: *P*(*A* or *B*) = *P*(*A*) + *P*(*B*) – *P*(*A* and *B)* ♦ the complementary rule: *P*(not *A*) = 1 - *P*(*A*) Probability problems using Venn diagrams, trees, two – way contingency tables and other techniques • Probability problems using Venn diagrams, trees, two – way contingency tables and other techniques, Probability problems using fundamental counting principles	