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Mathematics Support Program for Commencing Engineering Students between 1990 and 1996: an Australian Case Study*

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For the last twenty years or more higher education institutions have been concerned about the participation of students in engineering studies. Much of this concern centres around the ability of students to perform appropriate mathematics. This paper reports on the level of mathematical skills of engineering students entering a regional Australian university. In the seven years of the study, students have continued to have difficulties with estimation, fractions, indices, order of operations, graphs and basic algebra. The paper further reports on an intervention strategy which was designed to address these difficulties which has improved the success of participants repeatedly over the seven years of the program.

INTRODUCTION

FOR THE LAST twenty years or more, higher education institutions have been concerned about the participation of students in engineering studies. This has been fuelled by the anticipated shortage of engineers in the next century [1]. To increase retention rates, general models of retention in higher education have focused on both direct and indirect factors and are exemplified by the work of Tinto [2, 3] and Pascarella [4]. It is suggested and supported by research [5] that factors linked to retention could be students' personal and academic characteristics, as well as institutional characteristics and environment.

However, in the nineties with the advent of mass education and an increase in the diversity of the student population, problems related particularly to academic preparedness began to be documented. In Australia, McInnes and James [6] declared:

> a major problem for many staff teaching first year, in addition to increasing spread of student abilities, is the uneven preparedness within a student population. This uneven preparedness, perhaps in terms of specific topics or techniques, means that selecting a suitable starting place is problematic for first-year subjects.

Internationally, other researchers became concerned about the knowledge and skill level of students studying engineering mathematics. A national UK report [7] on mathematics matters in engineering stated that 'students are now less well prepared that 10 years ago . . . evidenced by lack of confidence at understanding algebraic manipulation and reduction of graphing skills'. Similar concerns were shown around the world [8, 9, 10]. Gardner and Broadus [11] working with US college students also found that 'mathematics was the basic culprit in undermining student academic progress'.

In Australia in 1990, one university increased the number of first-year mathematics subjects from two to four to cater for changes in the mathematical abilities of its commencing students [12]. Today, universities still struggle with this uneven preparedness in mathematics as evidenced by the proliferation of mathematics learning centres, bridging programs and other support services throughout Australia [13].

In 1989 it became evident at the University of Southern Queensland (USQ – a regional university in Queensland, Australia) that commencing first-year engineering students were having the same problems with mathematics as students everywhere. As mathematics is essential for progression in Bachelor of Engineering studies an intervention program was initiated. The objectives of this program were to:

- provide students with knowledge of their readiness for studies of mathematics that they would encounter in their degree program;
- provide a mechanism for students to refresh their mathematics knowledge while still studying engineering;
- provide at-risk students with an alternative pathway of study early in their engineering studies;
- provide students contacts with other engineering students for mentoring and peer support;
- provide students with models for and advice on good study habits;
- improve students' success in first-year mathematics.

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This paper details the design, development, implementation and evaluation of this intervention program between the years 1990 and 1996.

BACKGROUND AND DESIGN OF PROGRAM

The program entitled the 'Engineering Refreshment Program' was initiated in late 1989 at the instigation of both mathematics and engineering staff. At that time, pass rates of full-time Bachelor of Engineering students in their first mathematics subject were low and affecting retention throughout the Bachelor of Engineering degree. The program was operated by the then Mathematics Education Centre, now Office of Preparatory and Continuing Studies (OPACS), as a support program, separate but linked with students' other studies in engineering, and focused on the readiness of commencing students to study first-year mathematics. The program's four distinct stages included orientation, testing, diagnosis and refreshment.

Orientation consisted of a presentation with engineering staff to all first-year engineering students during the week prior to commencement of lectures. All students were instructed on the importance of mathematics to success and to attend testing sessions which were provided during the nights of the first week of lectures. To reduce pressure on the students, two sessions of three hours each were available, although most students required only one to two hours to complete. Students were tested on their knowledge of arithmetic, graphing, algebra, matrices, geometry, trigonometry, differentiation and integration at levels deemed necessary for commencing students. An experienced mathematics lecturer then marked the test and produced a diagnosis of the level of readiness of a student. If students could not demonstrate acquisition of required knowledge in this test then they were instructed to refresh their knowledge by studying a set of mathematics modules associated with the topics tested. At this stage a minority of students, usually one or two each year, were advised that they were not ready for engineering mathematics, and after consultation with engineering lecturers, were recommended to complete a year-long preparatory mathematics program before they continued with the mathematics-based subjects of their course.

In the refreshment phase of the program students purchased a set of materials and were asked to study up to 8 modules of mathematics. Each module was concerned with one of the topics tested previously and was designed to be a set of self-paced instructional materials. When students thought they had mastered a topic they were required to take a short quiz (30 minutes). Students could attempt a quiz as many times as necessary to master the topic. Mastery was assessed by teaching assistants and tutors who marked the quizzes on the spot, giving instant feedback and tutorial assistance to the student. Reports on the progress of students were passed regularly to the students' supervisors. The program continued for the first five weeks of the first-year mathematics subject and was undertaken at the same time as the delivery of lectures and tutorials for that subject. Completion of the program was timed to coincide with the last date on which students could drop a unit without academic penalty so that students, in consultation with their supervisors, could decide if they needed more time to prepare for the study of mathematics-based engineering subjects. This was particularly relevant for mature students who often returned to full-time study after an absence and may not have recently studied mathematics.

Teaching assistants for the program were recruited from past engineering students, usually in year 3 or 4. Criteria for selection included a recommendation from faculty staff, an excellent academic record especially in mathematics and acknowledged ability as an effective communicator. These students were used as peer tutors to assist the regular tutors and were encouraged to reinforce to students the importance of a solid understanding of mathematics for engineering studies. Also, it was observed that the peer tutors provided other support in the form of advice on study skills, time management and information about studying engineering, that first year students would only seek from a fellow student. Teaching assistants were provided with a half-day training workshop to prepared them for their new mentoring role.

Students were encouraged to continue to contact OPACS if they had problems within engineering related to numeracy misconceptions.

CHARACTERISTICS OF COMMENCING STUDENTS

Students enrolling in full-time on-campus Bachelor of Engineering studies at USQ are typically between the ages of 17 and 25. Ninety per cent are recent school leavers while many are the first in their family to enter university studies [14]. The mathematics prerequisite for entry into Engineering studies at USQ is the Queensland secondary school subject called Maths B (or equivalent). This is a rigorous subject which introduces students to calculus and other formal mathematics topics. Maths C another Queensland secondary school subject extends a student's understanding of calculus using many topics previously studied in Maths B. Of the recent school leavers enrolled in the Bachelor of Engineering course, students have increasingly opted to study engineering after studying Maths B only. Percentages studying both Maths B and C have dropped over the years of this study from 84% to 71% of recent school leavers. Although mathematics background of recent school leavers has exhibited some

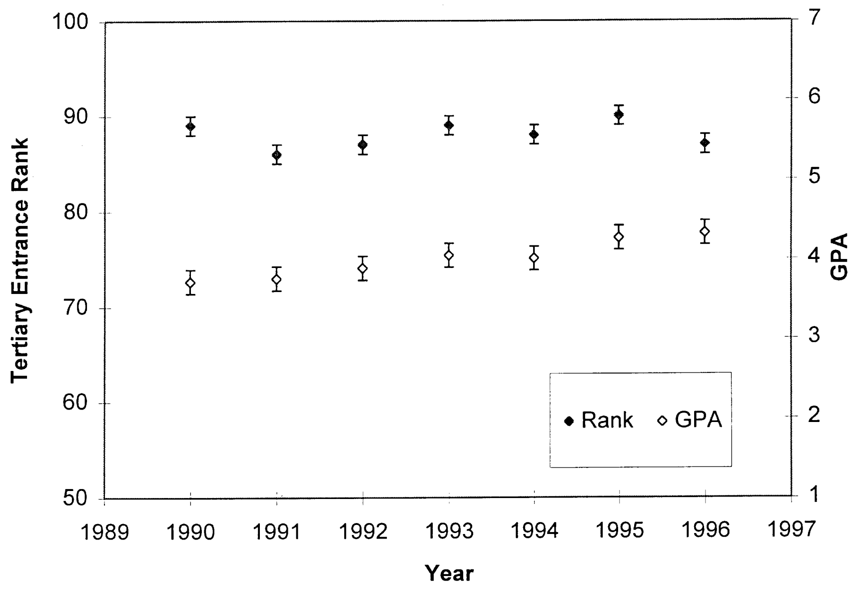

Fig. 1. Tertiary entrance ranks (SE) and GPA (SE) of students entering engineering between 1990 and 1996.

changes, the overall level of academic ability of students as measured by their Queensland Tertiary Entrance Rank (a score ranging between 50 and 99) has not changed markedly over recent years (Fig. 1). Similarly, the grade point average (GPA) – a score between 1 and 7 – of students calculated from the grades obtained in all enrolled subjects throughout a degree has also exhibited little change over the past seven years. These two measures indicate that the overall standard of students commencing engineering over the past seven years has changed little.

Mathematics proficiencies were also measured at the time of the students' entrance to engineering. A total of 563 students were involved in the study (Table 1). As previously described, all students were instructed to attend a testing session at the beginning of the semester. This test consisted of two parts. Test 1 consisted of a test addressing the students' understanding of basic arithmetic and graphing (Table 2). Item analysis of this part of the test for students enrolled between 1991 and 1996 (1990 data not available) indicated that students consistently had problems with the highlighted questions. These included topics of estimation, fractions, exponents, order of operations and straight line graphs and equations. The second part of the test (Test 2, Table 3) was more extensive and examined the students' current ability to answer questions in school-level algebra, matrices, geometry, trigonometry, differentiation and integration. Analysis of the numbers of students who had not mastered these topics indicated that many students required refreshment before they attempted their university mathematics.

Detailed data were not collected between 1990 and 1993 but between 1994 and 1996 less than 25% of students had mastered the five mathematics topics essential for university mathematics (Fig. 2). The results indicate that students were better in 1996 than in other years. If the test is examined question by question, similar patterns were apparent over the seven years of the study. These are typified by the results from 1996 – the best year (Fig. 3). In this year more than 50% of students

Table 1. Number of students in the Engineering Refreshment Program over the past seven years.

Year	1990	1991	1992	1993	1994	1995	1996
Number	92	124	106	69	74	47	51

Table 2. Question assessing basic arithmetic and graphing. Highlighted questions are those students had most difficulty with.

Number	Test Question
1	Place numbers in order from smallest to largest: $3, -2, 1.5, -2\frac{1}{4}, \sqrt{5}, -\sqrt{2}$
2	Give three values which satisfy $p \geq -5$
3	Round 3256 to nearest hundred
4	Round -0.0652 to its leading digit
5	Complete $24 \div ? = -6$
6	Estimate $56 + 23 \times 9246 + 12$
7	Express $\frac{5}{6}$ as an equivalent fraction with a denominator of 24
8	Express $\frac{1}{8}$ as a decimal
9	Find 8% of 330 mL
10	Simplify the ratio 24:14
11	Simplify $\frac{1}{4} \div \frac{5}{6} + \frac{3}{4} - \frac{5}{2} \times \frac{4}{3}$
12	Evaluate $27^{5/3}$
13	Simplify $(-2)^5 \times (-2)^{-6}$
14	Simplify $-3(2-8)$
15	Evaluate $\{20 - 3[3 \div \frac{12}{4}]^2\}^3$
16	Evaluate 2^0
17	Write an equation for a straight line with a slope of -4 and y intercept of -1
18	Write an equation of the straight line drawn on the graph below.......
19	Sketch the graph of $y = -\dfrac{x}{2} + 2$
20	Draw the graph of $y = x^2 + 7x + 6$

Table 3. Test 2 assessing more advanced pre-tertiary mathematics topics. Highlighted questions are those students found most difficult in 1996.

No.	Question
1	Express $\frac{16(a^2b^4)^{-1/2}}{b^{-3}}$ as a simple fraction
2	Express 0.0000026 km in mm
3	Expand $(x+1)(-2x+1)(x-3)$
4	Factorize $6x^2+x-12$
5	Make t the subject of the equation $y=(8t+3)^3+4$
6	Make x the subject of the equation $y=3e^{-x}+2$
7	Find $\log_7 9$
8	Solve the quadratic equation $3x^2+4x-8=0$
9	Solve the following set of simultaneous equations for x, y and z.
10	If $A=\begin{bmatrix}2 & 1 & -1\\ 1 & 0 & 3\end{bmatrix}$ and $B=\begin{bmatrix}1 & -3\\ 0 & 2\end{bmatrix}$. Find A + B (if possible)
11	Find AB (if possible)
12	Find $3B^T$
13	Find the inverse of $\begin{bmatrix}1 & 0 & 2\\ 0 & 1 & 2\\ 0 & 4 & 9\end{bmatrix}$ if it exists
14	In the matrix equation AX = B, $A=\begin{bmatrix}1 & 1 & 1\\ 2 & -3 & 1\\ 4 & 1 & 3\end{bmatrix}$ and $B=\begin{bmatrix}1\\ -2\\ 3\end{bmatrix}$. If the inverse of A is $1/2\begin{bmatrix}-10 & -2 & 4\\ -2 & -1 & 1\\ 14 & 3 & -5\end{bmatrix}$ find X
15	Find the equation of the straight line passing through the points $(-3,1)$, $(-1,-2)$
16	Determine the centre and radius of the circle $x^2+y^2-2x+3y=25$
17	What is the equation of the hyperbola with a vertical asymptote at $x=1$, and horizontal asymptote at $y=-1$, passing through the point $(2,3)$
18	Sketch the graph of $y=(x-3)^2+4$
19	Indicate by a labelled sketch how you would graphically solve the equation $x^2-1=\ln x$
20	Find all the angles between 0° and 360° that satisfy the equation Sin A = 0.4
21	In the triangle below find x *(triangle drawn)*
22	Convert 329° to radians
23	On the same set of axes sketch the graph of $y=\sin x$ and $y=\cos x$ for $-2\pi \le x \le 2\pi$
24	Complete the following statements: $?+\cos^2\theta=1$ and $1+?=\sec^2\theta$
25	A surveyor attempting to find the height of a vertical cliff makes the following observations: *The angle of elevation from the ground to the top of the cliff is 30° at a certain distance away from the bottom of the cliff. But, the angle of elevation is 45° when 20m closer to the cliff.* What is the height of the cliff?
26	Differentiate the following functions with respect to: x $2\sqrt{x}-\frac{4}{x}+10$
27	Differentiate the following function with respect to x: $\cos^2 x$
28	Differentiate the following function with respect to x: x^2e^{3x}
29	Find the local maximum value of the function $y=3+6x-x^3$
30	Find $\int\left(\frac{5}{x}+2\cos x+4\right)dx$
31	Find $\int(3e^x+4\sin x)dx$
32	Evaluate the following: $\int_0^{\pi/2}(\sin A-\cos A)dA$
33	Find the area enclosed by the curve $y=x^3-5x^2+6x$ and the x-axis

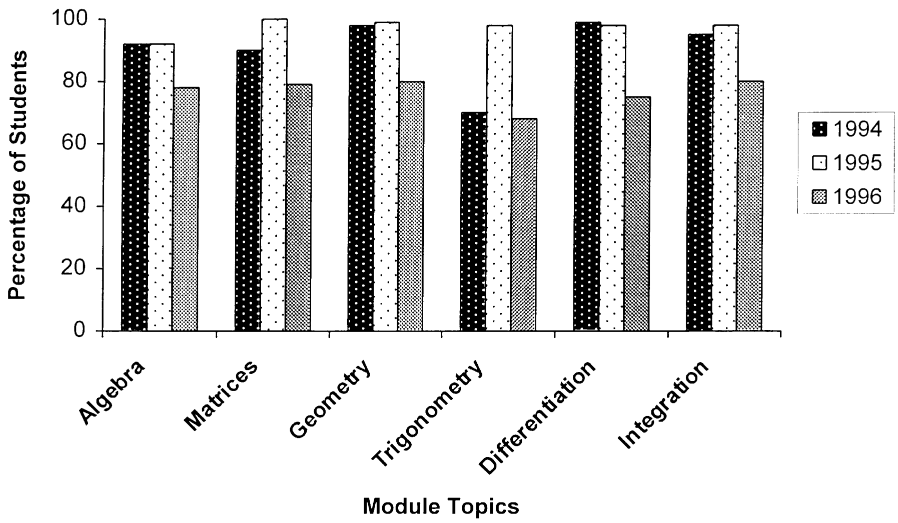

Fig. 2. Percentage of students required to study a mathematics module 1994 to 1996.

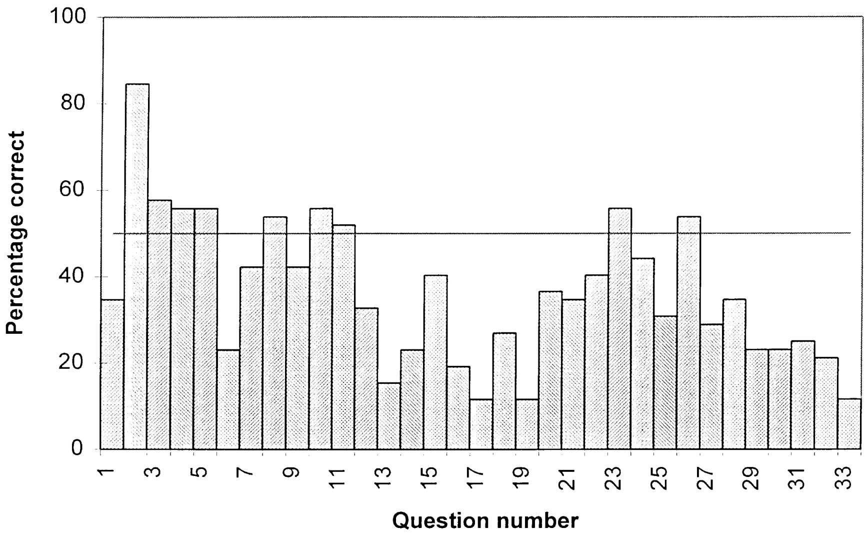

Fig. 3. Percentage of students with questions correct in Test 2 1996.

were correct in only nine out of thirty three questions. In the remaining twenty four questions, the questions with which most students had difficulty (less than 25% correct) include the topics of rearranging formula (Q6), solving matrix equations (Q13, 14), graphing of parabolas, circles and hyperbolas (Q16, 17, 19) and integration (Q30–33). By far, the lack of ready recall of algebra and graphing skills is the most worrying. Anecdotal evidence from mathematics and engineering lecturers teaching these students confirmed the accuracy of the above results.

EVALUATION OF THE SUPPORT PROGRAM

Although it is not compulsory for students to participate in this support program, of the 563 students tested between 1990 and 1996, 84% took advantage of the service and have completed the majority (>80%) of the modules recommended. 74% of students who have participated in the program over its seven years went on to pass their first-year mathematics subject compared with only 45% passing from the group who didn't participate. This level of success was consistent over the seven years of the study.

The question arises as to whether or not it is the intervention program causing the students to be successful in mathematics or some other factor such as Tertiary Entrance Rank (a measure of past academic achievement) which is affecting students' success rates. It is clear that although the range of Tertiary Entrance Ranks (75 to 99) is the same for groups of students who participate and those who do not, the mean ranks for each group in each year of study are significantly different (Table 4; ANCOVA, $P_{1,1,476}<0.001$). That is, students who participate have been successful in the past. However, when analyses of covariance were performed comparing either grade in mathematics or GPA with factors, year (1990 to 1996) and participation in the program, with Tertiary Entrance Rank as a covariate, then in both cases participation and year had a significant effect on grade or GPA (ANCOVA, $P_{6,1,1,465}<0.0001$), although the interaction between year and participation was not significant. This means that when the effect of Tertiary Entrance Rank is removed, by including it as a covariate of grade or GPA, then the effect of participation in the program is highly significant and, although the magnitude of this effect differed between years, the interaction between year and participation was not significantly different.

A summary of this in Fig. 4 clearly shows that the percentage of students passing the unit is much higher for all groups of entrance ranks, if the students have participated in the support program, but is particularly important for students who have lower ranks between 75 and 85. Other factors such as level of maths achieved before participation and years since study were found not to be significant using similar statistical methods.

Anecdotal evidence supports these findings. Engineering academics over the past seven years have repeatedly related cases of students who have been underprepared for engineering. The faculty's continual strong support for the program at all levels means that it is satisfying the needs of the faculty.

Table 4. Tertiary entrance rank (mean SD and range in brackets) of students in relation to participation in the Engineering Refreshment Program and success in their first year mathematics subject.

	TER of participants	**TER of non- participants**
Fail maths	85 ± 5 (76–99)	83 ± 5 (76–96)
Pass maths	90 ± 6 (75–99)	88 ± 6 (76–99)

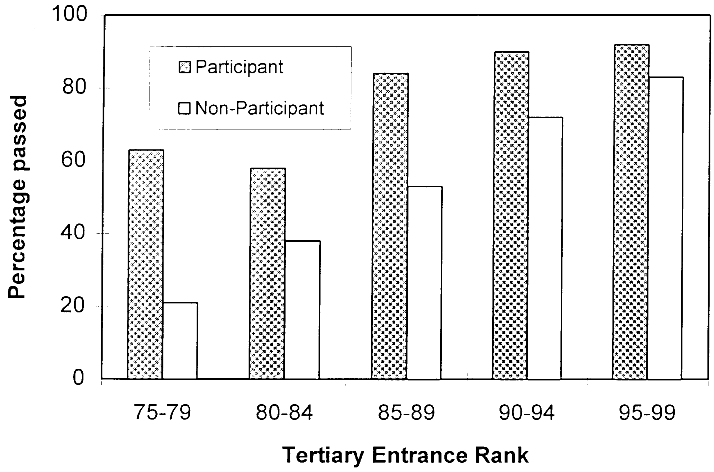

Fig. 4. Comparison of success rates of participants and non participants by Tertiary Entrance Rank.

Commencing students have mixed reactions to the program. Many feel that such a program is unnecessary and a duplication of school studies. Yet results of the test at entry indicate that students require some refreshment of past knowledge at the commencement of university mathematics. Past participants who return to the program as peer tutors often state that although they hadn't appreciated it at the time, the program was a golden opportunity to refresh high school knowledge quickly.

Overall, analysis of the success rates of students who participate in the program and assessment of staff and students' reactions to the program indicate that it is thought to be a useful intervention strategy.

CONCLUSIONS

The mathematical abilities of commencing students were a concern when the program began in 1990 and have not changed significantly over the seven years of the study. However, they are not atypical and are similar to those reported elsewhere in both regional and city universities in Australia [15, 16, 12]. Commencing engineering students do not have ready recall of many topics in mathematics even though they have reportedly mastered them in the past, in some cases as little as six weeks previously. The topics of most concern are those associated with the basic skills of estimation, algebra and graphing (Test 1). It might be expected that students would not be able to solve complicated calculus problems as in Test 2, but it is worrying that some cannot quickly solve a linear equation, draw a straight line graph, estimate an answer or manipulate exponents. It is clear then that mathematics standards of students have not dropped over the seven years of the study, but have remained at a constantly low level.

However, although commencing students' mathematical abilities do often fail to meet lecturers' expectations the implementation of the engineering refreshment program has improved the situation. It has achieved successfully all of its objectives, as stated in the introduction of this paper, in every year of its operation.

It is clear that overall, if students participate in the program, then their chances of passing the unit are improved. It is particularly important for the students that come with the lowest entrance ranks, but still has an effect on students with the highest rank. This result is consistent and was reproducible for each of the seven years of the program. The question as to why the program is so successful is not, however, quite as clear. We believe that the nature and timing of the program offer students the opportunity to recapture lost knowledge and reinforce the mathematics lectures. Another important aspect of this program is that it provides students with a place where they can make contact with more advanced successful engineering students and where they can get information on what it takes to become successful in engineering at the same time they are getting mathematics and study skills help.

Past retention studies indicate that many factors, particularly institutional and personal management aspects, are involved in success in tertiary study. This study indicates that preparedness for university mathematics must still be one of those factors.

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