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Chances of success in and engagement with mathematics for students who enter university with a weak mathematics background

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An increasing number of Australian students elect not to undertake studies in mathematical methods in the final years of their secondary schooling. Some higher education providers now offer pathways for these students to pursue mathematics studies up to a major specialization within the bachelor of science programme. This article analyses the performance in and engagement with mathematics of the students who elect to take up this option. Findings indicate that these are not very different when compared to students who enter university with an intermediate mathematics preparation. The biggest contrast in performance and engagement is with those students who have studied mathematics in senior secondary school to an advanced level.

Keywords: mathematics background; bridging mathematics; first-year mathematics; performance in university mathematics; engagement with mathematics

1. Introduction

The review of mathematical sciences in Australia raises some serious concerns about the mathematics skill base of this country, and calls for the development of 'an appropriate vision and spark an Australian renaissance in this field' [1]. A particularly concerning indicator is the decline in the number of graduates with strong mathematical skills over the past two decades [2]. This is a worldwide phenomenon; the decline of graduates in mathematics and other fundamental sciences has been documented by the Organization for Economic Cooperation and Development (OECD) at the Global Science Forum held in 2005 [3], and similar reports have been produced in the USA [4] and in the UK [5].

One of the major difficulties with raising the mathematics skill base is the under-preparedness of students entering higher education, which results in low levels of success and engagement with university level mathematics. The increasingly weaker mathematics background of university entrants and its consequences have been reported around the world. Examples include studies in the US [6–8], in the UK and Ireland [9–11], in Australia [12], in Sweden [13] and in Hong Kong [14].

In order to attract more students to mathematics and mathematics-based disciplines, and to improve retention, universities have been addressing the

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under-preparedness in mathematics of their incoming students with bridging or remediation programmes and, more generally, with programmes that support student transition from secondary school to university mathematics study. The literature documents numerous efforts made around the world to prepare students for the challenges of university level mathematics study and to provide a larger number of students with the opportunity to pursue mathematics studies (see [15] for an international overview of such programmes, [16] within Australasia and [17] for studies within the US). Increasing additional support has also been provided by some universities through learning centres to help students with the learning of mathematics [18,19]. The difficulties with transition to formal thinking have been recognized and models for understanding that transition better have been developed (see, e.g. [20,21]); it has been shown that the use of innovative and effective teaching methods is important to bridge the cultural gap between secondary and university mathematics [22,23].

Various measures of success with improving students' performance in and engagement with university level mathematics, particularly in the first year, have been investigated. Some of these belong to the psychology domain. For example, confidence levels and self-motivation have been recognized as important factors in student success in mathematics studies and are a continuous subject of research [24,25].

Other various studies analyse the effectiveness of performance in tests or in previous mathematics studies as predictors for successful transition to university level mathematics and continuous engagement with the subject. For example, Eiselen et al. [26] designed a simple diagnostic test which proved to be a predictor for student success in a first semester university mathematics course. In Australia, Rylands and Coady [27] compared student performance in first year mathematics courses with performance in senior secondary school mathematics and with their tertiary entrance score, to conclude that only performance in senior secondary school mathematics correlates with success in first year mathematics. Wilson and MacGillivray [12], also in Australia, compared the results of a questionnaire administered to a large number of first year science students undertaking a statistics course with their senior school mathematics background to conclude that in order to have full and confident use of basic, pre-senior mathematical skills; algebra-based mathematics needs to be studied beyond this level.

Finally, for those students who undertake a bridging or remediation programme as they enter university, successful completion of such programme has also been proven to be a predictor for success in further studies and engagement with mathematics. A major study in this area comes from the USA where Bahr [17] analysed the efficacy of US remediation programmes. Bahr analysed the data of students in 107 colleges to find that the long-term outcomes of students who entered college under-prepared and successfully completed a remedial programme compared with those who entered college with adequate mathematical preparation.

2. A study in the Australian context

In Australia, students choose to study mathematics in senior secondary school, and those who opt to do so can take these studies to three different levels. The choice of mathematics courses varies by state, from elementary to intermediate and to

advanced levels [28,29]. The elementary courses normally cover an introduction to data analysis, fundamental concepts of graphs and relations, geometry and trigonometry, matrices and business-related mathematics; these courses are intended for students who would not require mathematics in their future career. The intermediate and advanced courses deal with mathematical methods that are founded on calculus concepts and techniques. The intermediate level courses introduce the fundamental calculus concepts of differentiation and integration involving simple functions, while the advanced courses expand on the differentiation and integration techniques and on the family of functions to include transcendental functions and their inverses, and introduce modelling with simple differential equations.

Students without the knowledge of calculus (i.e. those who have not achieved the intermediate or advanced levels referred to above) have traditionally limited their university study options and have closed their access to many programmes, including science, engineering, information technology and business. However, this is now becoming less of a problem. In response to the declining number of students who undertake mathematics in senior secondary school, in the past decade universities have progressively changed their programme prerequisites; they prefer to attract to their disciplines more students who are academically strong, regardless of their mathematics background. In other words, universities have enlarged the pool from where they select candidates by watering down the programme prerequisites. For example, engineering programmes have largely changed the prerequisites from advanced level mathematics to intermediate level, and most bachelor of science programmes in Australia now admit students without senior school mathematics. This change in prerequisite requirements has in turn further exacerbated the problem of low uptake of secondary level mathematics: over the years, students have progressively shifted away from advanced level mathematics to the intermediate and elementary levels [29,30]. There is the perception that it is harder to get good marks in intermediate and advanced mathematics, and so students favour elementary mathematics in order to maximize their secondary rank used for the competitive admission to university programmes. Consequently, fewer students now come to university with advanced level mathematics, and a large proportion of students come with no senior mathematics school or only background at an elementary level, i.e. they come without the basic calculus concepts and techniques.

Most Australian universities accommodate the uneven and generally lower level of mathematics preparedness of their students by offering first year mathematics courses at several levels. Students who enter university with advanced level mathematics can progress directly to what was traditionally first year university mathematics, while students with a weaker preparation must undertake first one or two introductory mathematics courses. This is not without controversy. Some academics, particularly in the research intensive universities, question whether it is the role of the mathematics departments to be teaching courses that have traditionally been in the domain of secondary schools (see, e.g. [31]). The counterargument is that universities need to adapt to reality, and that students who are admitted to university programmes should be able to upgrade their mathematics skills while at university, if required. Furthermore, such approach opens up opportunities to attract mathematics students who, for whatever reason, did not study mathematics in secondary school to an advanced level.

At the author's institution, there are no mathematics prerequisites for entry into the bachelor of science; incoming students are advised at the time of enrolment that this should not be a barrier for pursuing mathematics studies and that the diversity of mathematics backgrounds is catered for by providing three different levels of first year mathematics courses. In other words, students are offered pathways towards further mathematics studies, rather than remedial programmes. Students are reminded that everybody can 'do' mathematics if enrolled at the appropriate level, that adequate support will be provided to those who try and that they should not make their decisions solely based on their school experiences of the discipline.

The question addressed in this article is the likelihood that students who do little or no mathematics at all in senior secondary school will be able to engage with and succeed in mathematics once they are admitted to university. As referred to Section 1, work can be found in the literature that compares the mathematics performance at university with performance in senior secondary school levels (see, e.g. the case studies in Australia [27] and New Zealand [32]). Such comparison is not possible for students who did not do mathematics in senior secondary school. It is possible, however, to track students' performance in and engagement with mathematics for those who decide to take on mathematics studies once they enter university. Given the efforts put into developing and teaching courses at levels that were previously considered to be only in the domain of secondary schools, it is pertinent to ask the following questions:

What are the chances of success for students who 'taste' university mathematics and who have done little or no mathematics at all at senior secondary level?
What are the chances that these students will engage with further mathematics courses?
Are these chances any different for the students who have done calculus in senior secondary school?

In an attempt to answer these questions, this article analyses 6 years of enrolment and performance data of university students who started mathematics studies at each one of the three levels offered at the author's institution. It compares the performance of the students who entered university with little or no mathematics studies in senior secondary school with those who undertook intermediate or advanced level studies, and tracks their enrolment and success in further mathematics courses.

3. Methodology

Students at the author's institution can start studies in mathematical methods at three different levels – preparatory, intermediate and advanced – matching the three different levels of preparedness they bring when entering university. These three levels correspond to the three courses in mathematical methods offered by the School of Mathematical Sciences – *Functions and their applications, Analysis of change*, and *Mathematical techniques for modelling* – which for the purpose of this article will be referred to as MM1, MM2 and MM3, respectively. The preparatory first year mathematics course MM1 is for students who have not studied calculus in their last secondary school year; these students would have only taken the elementary course or no mathematics at all in their senior secondary schooling. Students who enter

Table 1. Pathways into level two mathematics.

Pathway	Level one mathematics courses to be taken before proceeding to level two mathematics	Highest level of senior secondary mathematics attained
1	MM1 + MM2 + MM3	None or elementary (no calculus)
2	MM2 + MM3	Intermediate (basic calculus)
3	MM3	Advanced (advanced calculus)

university with a basic calculus background enrol in the intermediate mathematics course MM2 and those who have reached the advanced mathematics level commence with the advanced mathematics course MM3. These three courses must be taken sequentially, i.e. MM1 is a prerequisite for MM2, and this course is in turn a prerequisite for MM3. Each course is of one semester duration, and therefore, students take at most a pair of them in their first year. Students have access to other level one mathematics courses such as statistics and discrete mathematics, but anybody who wishes to undertake major or minor studies in mathematics must undertake MM3. In summary, there are three pathways to level two mathematics courses, consisting of one, two or three courses, as summarized in Table 1.

These options have been available since 2000 and so there is now sufficient data to analyse the progression of the students who came through the system and attempted at least one of the three courses in mathematical methods.

For the purpose of this analysis, only students who had the choice to do courses in mathematical methods as part of their university programme were considered. Programmes where the study of mathematical methods is a compulsory component (e.g. engineering or computer science) have not been included because the engagement with mathematics of students enrolled in such programmes cannot be assumed to be voluntary. Therefore, only data pertaining to students undertaking the bachelor of science or one of the combined programmes of science with education or with arts form a part of this analysis. In these programmes, students who do not wish to study mathematical methods have the choice to take either a traditional level one statistics course (which requires basic calculus taken at senior secondary school) or a course on statistical reasoning (which does not require any mathematics at senior secondary school level); this pathway usually appeals to students who intend to major in the life sciences and have no intention of pursuing further mathematics studies.

Students enrolled in the bachelor of science must complete major studies in an area of science (at least eight courses), and minor studies in another area of science (at least four courses). Given the wide range of science courses offered, students can take many different pathways towards completing the bachelor of science (one of them being a specialization in mathematics), and so some assumptions must be made when analysing the data. First, given the freedom of course choice, it is appropriate to assume that students who choose to take a course in mathematical methods in their first year at university do so with the intention to complete a minor or a major sequence in mathematics. Second, it is also appropriate to assume that those who try a level one course in mathematical methods in their second year at university, may intend to complete minor studies in mathematics, as they still have room in their programme to do so. With these two assumptions, and considering that it normally

takes 3 years to complete a bachelor of science, the analysis was restricted to students who commenced their studies of mathematical methods at one of the three possible levels within their first 2 years at university, and between 2000 and 2006, as these students would have had time to complete a minor or major in mathematics by now (more precisely, by the end of 2008, the end year of the data set).

Once the data set was narrowed down as described above, students were classified into three categories according to the first level one course in mathematical methods they took. Table 2 shows the size of these three groups of students who commenced their studies in mathematical methods in the period from 2000 to 2006. Hereafter these groups will be called MM1, MM2 and MM3 to indicate the students who commenced their university studies at one of the three respective levels. Given that the numbers are too small to make a meaningful comparison year by year, each cohort was analysed over the whole 7-year period.

4. Results

Over the 7-year period, the MM1 and MM2 groups had similar success rates when attempting their first course in mathematical methods at the university level, with about a quarter of the students failing the course (Table 3). In contrast, only 12.6% of the MM3 group failed the course MM3, as shown in the same table. This table also shows that students in the MM2 group who failed MM2 were more likely to attempt the course for a second time.

To measure the success of engagement with further mathematics courses, an analysis was made of the total number of mathematics courses undertaken by the students in each group (Table 4). In each of the first two groups, MM1 and MM2, about 31% of the students did not attempt any further mathematics courses, 38.9%

Table 2. Number of students who commenced studies in mathematical methods at one of the three possible entry levels – preparatory (MM1), intermediate (MM2) or advanced (MM3) – over the period 2000–2006.

Group	Number of students
MM1	175
MM2	646
MM3	587

Table 3. Percentage of students who attempted their first course in mathematical methods more than once, and percentage of students who failed the last time they attempted it.

Group	Percentage repeated	Percentage failed
MM1	2.3	25.0
MM2	10.1	27.2
MM3	5.2	12.6

and 40.4% undertook one more course; 7.4% and 5.6% completed four courses and 5.7% and 9.1%, completed eight or more courses. It needs to be noted that some of the further courses undertaken by these students were level one courses that do not require a specific mathematics background (e.g. courses that cover topics such as 'numbers, logic and graphs' or 'the nature and beauty of mathematics'). The summary in Table 5 shows that about 40% of the students in the MM1 and MM2 groups progressed towards the next level (i.e. to MM2 and MM3, respectively), and hence did a year of mathematics studies. However, more students from the MM2 group attempted level two courses (22%, compared to 13.7%) and to level three courses (11.9% compared to 6.3%). On the other hand, almost 30% of the students in the MM3 group completed eight or more mathematics courses (equivalent to a major sequence), and 41.6% progressed to third year mathematics.

An analysis of the students' performance also provides some insight into their engagement with further mathematics. The performance profile of each of the three groups is presented in Table 6. As observed above, the MM3 group has the lowest number of students who failed their first mathematical methods course at the university level (i.e. obtained a mark less than 50 out of 100); this group also has the

Table 4. Number of mathematics courses undertaken by each of the three groups of students in the period 2000–2008, as a percentage of the number of students in the group.

	Total number of mathematics courses taken					
Group	1	2	3	4	Between 5 and 7	8 or more
MM1	31.4	38.9	12.6	7.4	4.0	5.7
MM2	31.0	40.4	9.1	5.6	4.8	9.1
MM3	22.6	16.8	9.3	7.2	16.1	28.0

Table 5. Percentage of students in each of the three groups who proceeded to the next level of mathematics studies.

Group	MM2	MM3	Level two courses	Level three courses
MM1	40.0	15.4	13.7	6.3
MM2		39.3	22.0	11.9
MM3			68.0	41.6

Table 6. Distribution of MM1, MM2 and MM3 grades for each of the three groups.

Grade	MM1 (%)	MM2 (%)	MM3 (%)
Fail	25.0	27.4	12.6
Pass	20.5	22.4	18.8
Credit	21.6	22.3	21.1
Distinction	14.2	15.2	22.1
High distinction	18.8	12.7	25.3

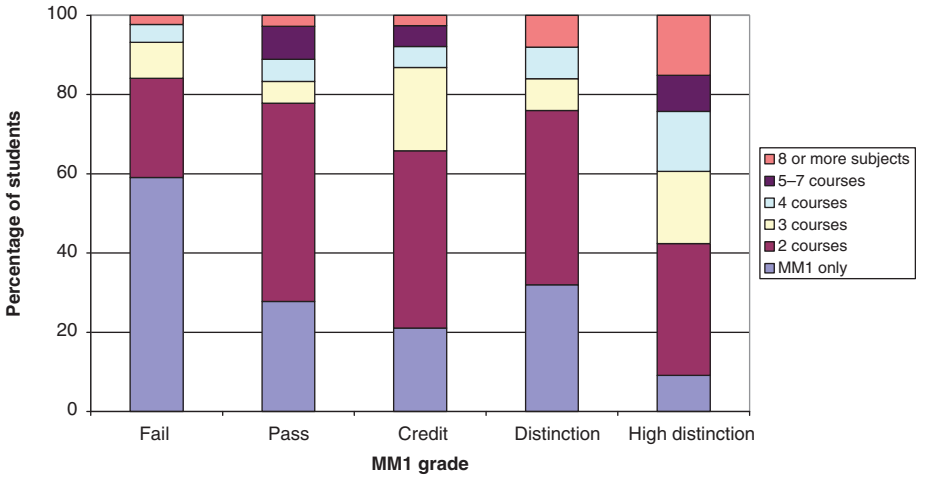

Figure 1. MM1 group: Distribution of students according to MM1 grades and total number of mathematics courses taken.

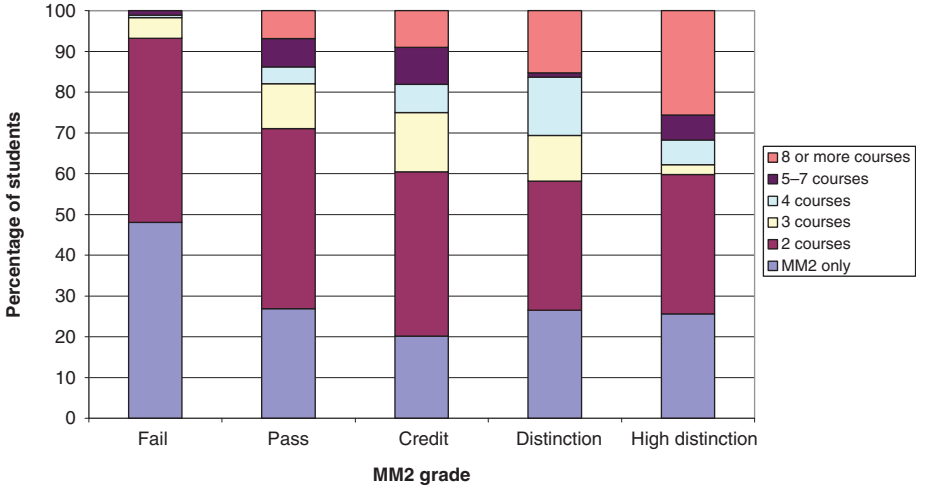

Figure 2. MM2 group: Distribution of students according to MM2 grades and total number of mathematics courses taken.

largest proportion of students with a 'high distinction' grade (which corresponds to a mark of 80 out of 100 or higher). There are, however, many students in the first two groups who also performed very well, 33% in group MM1 and 27.9% in the group MM2 obtained a 'distinction' grade or higher (i.e. a mark of 70 out of 100 or higher).

The relationship between student performance in their starting mathematics courses and the total number of mathematics courses they undertook is depicted in Figures 1–3, for the groups MM1, MM2 and MM3, respectively. In all three groups, students with the higher grades in their first course in mathematical methods tended to take further mathematics courses. Also, in all three groups, the percentage of

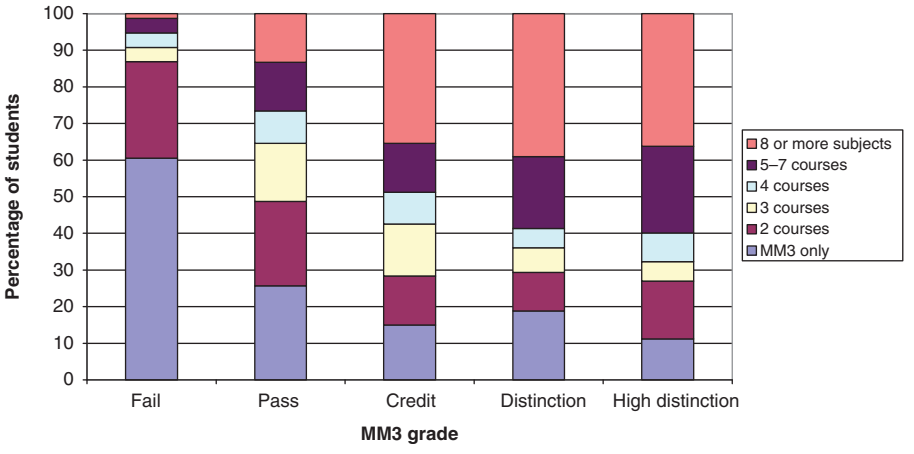

Figure 3. MM3 group: Distribution of students according to MM3 grades and total number of mathematics courses taken.

students who did only two mathematics courses is more or less consistent across the grade boundaries. In the MM1 and MM2 groups, the proportion of students who completed eight courses or more (the equivalent to a whole major in mathematics) increases with the grade, and more so in the MM2 group. On the other hand, in the MM3 group, this proportion is close to 40% for all three upper grades (credit, distinction and high distinction). The graphs also show that between 40% and 50% of the students who failed their first mathematics course at university tried other mathematics courses, and a few even completed a whole major sequence; the latter related to students who received a 'near pass' grade and were allowed to progress to the next level despite failing the course.

Finally, for students who did at least one further mathematics course, there was a positive correlation between their performance in their first mathematical method course and the average performance in all other mathematics courses (with r squared equal to 0.43, 0.42 and 0.45 for groups MM1, MM2 and MM3, respectively).

5. Discussion

Despite having done little or no mathematics at all in senior secondary school, some students decide to take the opportunities available to them to re-engage with mathematics when they enter university. The reasons behind such decisions are various, and are not in the scope of this article. 'Mathematics anxiety' or 'fear of mathematics' has been studied extensively elsewhere. It is also known, anecdotally, that some students simply do not do mathematics while at school because of the advice received from teachers, friends or parents, and they change their views about the value of mathematics as they mature; others discover too late that mathematics is fundamental to the discipline they would like to pursue, so they take the opportunity the university offers to start mathematics studies from the basics.

The results presented above shed some light over the chances of these students to engage with and succeed in mathematics, and provide evidence to address the three questions posed in Section 1 in relation to these students.

5.1. *What are the chances of success for students who 'taste' university mathematics and who have done little or no mathematics at all at senior secondary level?*

These results show that students who have done little or no mathematics at all in their senior secondary schooling can succeed in their first attempt at studying mathematics at the university level. Over the 7-year period included in this analysis, about one quarter of these students did not manage to successfully complete their first mathematics course. Although this percentage is rather high, it is not different to the percentage of students who came to the university with an intermediate mathematics background and failed their first course in mathematical methods taken voluntarily at the university. At the other end of the scale, about one-third of these students achieved high marks, and again, there were no differences between the two groups. In other words, the distribution of grades of these two groups is very similar. Students with at most an elementary mathematics background performed just as well as those with an intermediate background.

5.2. *What are the chances that these students will engage with further mathematics courses?*

The results also show that the first 'taste' of mathematics at university can be a successful start of a pathway towards completing a full minor or major sequence in mathematics. About 70% of these students undertook at least one additional mathematics course, although in almost half of these cases, this involved other level one mathematics courses that did not require a mathematical methods prerequisite. Forty percent proceeded to the next level of studies in mathematical methods (i.e. completed 1 year of mathematics studies), almost 14% studied level two mathematics courses, 11% completed up to a minor sequence, and almost 6% completed a major sequence. It is not a surprise that this engagement with further mathematics studies correlates with the students' performance in the first course; the higher the grades in the first course in mathematics methods, the larger the number of courses students attempted. Given that the sequencing of the various courses has been carefully planned, it is not a surprise either to observe a strong positive correlation between the marks in the first and subsequent mathematics courses. However, despite all odds, some students managed to successfully complete a minor or major even though they obtained only a pass or a near pass in their first attempt at studying mathematics at university.

5.3. *Are these chances any different for the students who have done calculus in senior secondary school?*

The one important difference between these students and those who entered university with intermediate mathematics (i.e. only basic calculus knowledge) is that these students were much less likely to repeat their first mathematics course if failed in the first attempt; in the great majority of cases, a failure in the course led to a complete disengagement from mathematics. The progression to further mathematics studies, both to the next level and to the same level of complexity, was very similar for the two groups. In both groups also, the likelihood of completing a major in mathematics increased with the grade received in their first mathematics courses, although the percentage of students who completed a major in mathematics was

slightly higher for the group with a higher pre-university preparation, and the percentage of these students who took their studies to level three was almost doubled.

The most pronounced differences are observed between these two groups of students – i.e. those without or with only intermediate mathematics – and the students who studied the highest level of mathematics at school. The success rate of this third group is much higher, with a half the failure rate, and overall significantly higher grades. Students who came to university equipped with advanced mathematical skills were also much more likely to engage with further mathematics studies, with almost 30% completing a major, and more than 40% taking their studies to level three. It might be argued that these students are more mathematically inclined, and this is what has led them to take the highest level of mathematics at school. However, this is also an argument for encouraging students to pursue advanced level mathematics studies while at school.

6. Conclusion

There are many more options available now in higher education for students who do not take up mathematics in their final years of secondary schooling and wish to 'taste' mathematics once they enter university, and continue with it as a major study in their programmes. In many Australian institutions, having gaps in the mathematics background is no longer an impediment to pursue a specialization in mathematics within a bachelor of science. The efforts made by the mathematics departments to cater for these students would seem to be justified, if the objective is to raise the general level of mathematics abilities of the science graduates. About one quarter of these students fail their first attempt to undertake mathematics studies and completely disengage from the course, but 40% complete at least a pair of course in mathematical methods as part of their university programme. This would have not been possible when programme prerequisites were much stricter and the mathematics pathway in higher education was only available to entrants with a strong mathematics background.

A rather surprising conclusion of this study is that the success in and engagement with mathematics of the students who did not study mathematics in their final years of secondary schooling does not differ greatly from the students who have undertaken senior secondary level school mathematics to an intermediate level. Both groups show equally poor success rates in their first course in mathematical methods taken as part of their university programme, and the percentages of those who pursue their studies up to a major are similarly low; although a higher percentage of students with a stronger foundation continue mathematics studies to the second-year level. The implications are that students who come to university with only an intermediate level of mathematics are as vulnerable to failure as those who come without or only with an elementary level; if they are to succeed they must be provided the same level of support.

Finally, this study strongly supports the recommendation made by the Australian Mathematical Sciences review to encourage students to do more mathematics in secondary school, and to 'increase the exposure of high school students to mathematics at various levels' [1]. Increasing participation in advanced secondary school mathematics could be the single most important factor that would change

around the trend of declining numbers of graduates with the high level mathematical skills necessary for the technological development of the world, to drive innovation and to educate the next generation of citizens. Students who take advanced mathematics levels in their senior secondary school years show higher levels of engagement with mathematics and are more likely to continue with mathematics studies to the completion of a major in programmes where mathematics is an option.

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