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Performance of students with weak mathematics in first-year mathematics and science

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In recent years, significant numbers of academics from the science and health disciplines at our institution have found that their students lack the appropriate 'mathematical' background to cope with first-year science subjects. Consequently, failure rates are on the increase in these subjects. The mathematical background of students entering university has been found to be a problem in other universities in Australia, as well as in the UK, Ireland and the US. In this report, the authors analyse data on current students' performance and present suggestions for addressing the problems found. The performance of first-year students in four different mathematics and mathematically related subjects is compared to the level of their secondary school mathematics and performance, and to their tertiary entrance score. We conclude that a student's secondary school mathematics background, not their tertiary entrance score, has a dramatic effect on pass rates. On the basis of our findings, a way forward is suggested.

Keywords: first year; performance; weak background

1. Introduction

For most bachelors degrees at most Australian universities a single number which measures a student's overall performance in school is the basis for making an offer of a place in the degree. In the state of New South Wales (NSW), Australia, this number is the Universities Admission Index (UAI). Most students in the first year of a bachelors degree in engineering, science, computing and health are required to study some mathematics or statistics. In all these areas students with wildly different mathematics backgrounds are placed into the same first-year mathematics, statistics or physics class. Some perform very well, but a distressingly large proportion fail.

Staff from the disciplines of science and health at the University of Western Sydney (UWS) have reported to mathematics staff that their students lack the appropriate mathematical background to cope with first-year mathematics and mathematics related subjects. Nursing staff complain that students are unable to calculate drug doses, engineers complain that students are coping badly with engineering mathematics and some cannot do even basic algebra, the scientists complain about the lack of algebra and poor performance in statistics of their students.

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Most believe that the situation is worse than it was a decade ago, and all are concerned about high failure rates.

Were the level of mathematics taught in first year to be lowered (many feel that this has already been done), students would gain fewer skills and be less prepared for later subjects. Lowering the standard of mathematics and mathematically related subjects goes against the philosophy of the report from the Australian Academy of Science in 2006 [1] which argues that the mathematical and statistical sciences in Australia are in crisis. Lowering expectations and requiring students to do another mathematics subject is often not possible because of crowded curriculums. In contrast to the problem of students with poor mathematics background, there is the additional problem that some students find the mathematically related subjects offered now are very easy.

The aims of this study were to find out, on the basis of a student's secondary school mathematics background, which groups of students were most at risk of failing first-year mathematics subjects and which groups, if any, could be expected to excel. The relevance of the tertiary entrance score was also considered. On the basis of our results, we suggest a way forward.

1.1. *Pre-university mathematics*

Students who have completed secondary school in NSW, Australia, and have studied mathematics have done one of

- Mathematics Extension 2 (previously 4 Unit Mathematics),
- Mathematics Extension 1 (previously 3 Unit Mathematics),
- Mathematics (previously 2 Unit Mathematics) or
- General Mathematics (replacing the 1981 Mathematics in Society and 1989 Mathematics in Practice syllabuses)

as part of their Higher School Certificate (HSC). The subjects are listed from most comprehensive to least comprehensive.

Forgasz [2] and Barrington and Brown [3] use a system of classification for secondary school mathematics in Australia that classifies each subject as Advanced, Intermediate or Elementary. Advanced subjects are described by Barrington and Brown [3] as

> ... generally taken by students who wish to proceed to tertiary studies that require the strongest of mathematical preparations, such as engineering, actuarial studies, mathematics, statistics and physical sciences. Such students normally undertake an intermediate mathematics subject (...) in conjunction with their Advanced mathematics subject.

Mathematics Extensions 1 and 2 are Advanced subjects. In NSW, students who take Mathematics Extension 1 sit the Mathematics exam as well as another exam. In this article Mathematics Extensions 1 and 2 will be considered together and referred to as Advanced Mathematics.

Barrington and Brown [3] also describe Intermediate and Elementary subjects:

> The State Boards also accredit Year 12 subjects which are suitable for students who wish to proceed to tertiary studies which require significant but not extensive mathematical preparation, such as science, medicine, economics/commerce, dentistry, agricultural science.

> The State Boards also accredit Year 12 mathematics subjects which are suitable for students who wish to study mathematics in their final year at secondary school, but do not intend to enter tertiary courses that require Intermediate or Advanced mathematics subjects.

Mathematics is an Intermediate subject, and will be referred to in this article as Intermediate Mathematics. General Mathematics is a non-calculus subject, and is Elementary; it will be referred to as Elementary Mathematics.

One of the aims of Elementary Mathematics given on the NSW Board of Studies website [4] is:

> Emphasis on the particular application of mathematics to finance and data analysis reflects uses of mathematics that are prevalent in modern society.

From this statement one could expect that students who have done Elementary Mathematics at secondary school would cope well with a first statistics subject at university, and perform better than those who had done Intermediate Mathematics.

1.2. *The mathematics problem*

Crowther *et al*. in [5] wrote

> Students entering university this year to study engineering, science and mathematics know less than they did 10 years ago, have trouble solving all but the simplest one-stage problems, need far more spoon feeding, cannot handle simple mathematical expressions and have little idea of the concept of proof.

Many academics at UWS would say that this complaint from Crowther *et al*. describes the situation today. However, Crowther *et al*. [5] in 1997 note that concern was being expressed about the mathematical deficiencies of engineering students as long ago as 1978.

The poor mathematical skills of students entering university to study engineering, science, or other disciplines in which mathematical skills are needed is the Mathematics Problem. The Mathematics Problem occurs in countries such as the UK, Ireland, Canada and Australia [6–9].

In a study based in Ireland, Hourigan and O'Donoghue [6] lament the deficiencies in mathematical skills in graduates of numerate disciplines and state that these students are clearly entering mathematics intensive degrees with poor basic mathematical skills. They note the implications for the student, institution and economy of what they say is becoming known in the UK as the Mathematics Problem.

Canadians Kajander and Lovric [7] have also identified problems with the mathematics preparation of their students:

> ... in spite of all efforts and energy ventured into pre-tertiary mathematics education, the knowledge and skills of incoming university students are far from satisfactory.

A UK report 'Measuring the Mathematics Problem', published under the auspices of four national bodies in 2000 [8] found, among other things, that

> The decline in skills and the increased variability within intakes are causing acute problems for those teaching mathematics-based modules across the full range of universities.

As part of the background it is stated that

> This past decade has seen a serious decline in students' basic skills and level of preparation on entry into Higher Education. . . .This decline presents a major problem in mathematics based degree courses right across the Higher Education sector – one which is widely acknowledged.

Australians Wilson and MacGillivray [9] say the following about students beginning university in a discipline such as science:

> It is generally assumed that the completion of an algebra and calculus based senior mathematics subject provides sufficient mathematical preparation for such a course.

However, Wilson and MacGillivray note that in recent years this assumption is not always true. These days staff at some universities are finding that many students enter science, health, and even engineering without any calculus. Is a non-calculus subject, for example Elementary Mathematics, sufficient preparation for disciplines such as science? This issue is addressed later in this article.

A part of the problem is believed to be that Australian universities are now enrolling students with increasingly diverse backgrounds. Students who would not have been able to gain a place in a university a generation ago now can. There are substantially more university places available now, and so a greater proportion of the population is studying at university. Is the lack of mathematical preparation a recent problem, brought on by taking not just the very best, but a broader sample of the population?

It should be noted that some of the blame for poor preparation in mathematics in Australia is given to the universities in [1]:

> Australian universities are lowering mathematics prerequisites and this is undermining enrolment in high school mathematics.

The Mathematics Problem has existed for some time. It has not gone away: it shows itself clearly in this study.

2. Method

The performance of students in various first-year university mathematics subjects and a first physics subject is analysed and compared to the level and performance of the mathematics studied at secondary school. For each first-year subject the final marks in that subject and the UAIs of the students were compared.

2.1. *Setting*

University of Western Sydney is a multi-campus university, with six major campuses in the west of Sydney and over 30,000 students. Some subjects are taught on several campuses, some on only one.

The first-year subjects considered in this study are by no means all first-year mathematics subjects available to students. They are compulsory for students in at least one degree and are also available to students to take as an elective. Students need not be in their first year to take any of these subjects.

Each subject is one-quarter of a full time load for one semester. A student who completes all compulsory assessment items in a subject is awarded one of the passing

grades H (high distinction, 85–100%), D (distinction, 75–84%), C (credit, 65–74%), P (pass, 50–64%) or the fail grade F.

2.2. *Participants*

Data for the following first-year subjects was studied:

- Discrete Mathematics (often compulsory for students studying IT/computing)
- Statistics for Business, a first statistics subject,
- Physics 1,
- Fundamentals of Mathematics, a basic mathematics subject designed to revise elementary mathematics and review/introduce calculus.

To enable the study to be restricted to students who were doing university mathematics for the first time and who had done secondary school mathematics recently, only students who had done some mathematics in the HSC the previous year were included in the study. More precisely, the data was restricted to students

- who enrolled in their degree in 2006,
- who were enrolled in at least one of the four subjects listed above in 2006,
- who did some mathematics in the 2005 HSC and
- who completed all compulsory assessments in the subject.

These criteria exclude students who were repeating the subject, those who were not in first year and those who dropped out part way through the semester.

The number of students who satisfied the criteria for each subject was: discrete mathematics 75, statistics 324, physics 170 and basic mathematics 310. The proportion of these students with the various levels of secondary school mathematics is given in Table 1. Note that the numbers in all tables have been rounded to the nearest integer.

2.3. *Data collection and management*

The university provided data on the secondary school mathematics subject and mark, and UAI, for all students who commenced their degree in 2006, and who were enrolled in the selected subjects in 2006. The results for all students in the selected subjects were obtained separately. The files were merged; the HSC information and university results were obtained for all students who satisfied all the criteria above.

Fewer than half the students who enrolled in a subject satisfied all the criteria given in the previous section for inclusion in the study, and for the statistics subject it was less

Table 1. Percentage of students with given background.

Mathematics background	Advanced (%)	Intermediate (%)	Elementary (%)
Discrete mathematics	21	45	33
Statistics	18	40	43
Physics	28	49	23
Basic mathematics	9	44	47

than one-third: some students had previously attempted the subject, some were not doing it in their first year, and some had not completed school in NSW in 2005.

In the analysis, the two advanced HSC mathematics subjects were combined because of the small number of students doing the more advanced of the two.

2.4. *Results*

The percentage of students who passed each university subject under consideration was calculated for each HSC cohort and is shown in Table 2. The percentages range from 100% of the students with a secondary school Advanced Mathematics background passing the basic mathematics subject (27 students) to 23% for those with an Elementary background in the same subject.

Table 3 shows the number of students who gained a passing grade better than a 'P' as a percentage of all students. This table indicates that higher levels of school mathematics result, overall, in better performance in the university subjects considered. The complete information about the proportion of grades awarded for each first-year subject is shown in Figures 1–4.

Correlations between performance in school mathematics and in the university subjects were calculated and the significance level was taken to be 0.01.

In the discrete mathematics subject there is a significant positive correlation with the marks of students in Intermediate Mathematics (0.51). There is no significant correlation between students' marks in Elementary Mathematics or Advanced Mathematics and their marks in discrete mathematics.

There is a significant positive correlation between students' marks in the statistics subject and their marks in Elementary Mathematics (0.38). There is no significant correlation with the marks from Intermediate Mathematics or the marks from Advanced Mathematics.

For the physics subject there is a significant positive correlation with both Intermediate (0.32) and Elementary Mathematics (0.56). There is no significant correlation between the Advanced Mathematics and the physics marks.

Table 2. Percentage of students who passed each university subject.

Mathematics background	Advanced (%)	Intermediate (%)	Elementary (%)
Discrete mathematics	88	65	36
Statistics	81	73	63
Physics	79	63	35
Basic mathematics	100	79	23

Table 3. Percentage of all students with grade better than 'P'.

Mathematics background	Advanced (%)	Intermediate (%)	Elementary (%)
Discrete mathematics	25	21	0
Statistics	44	34	29
Physics	47	26	8
Basic mathematics	67	37	5

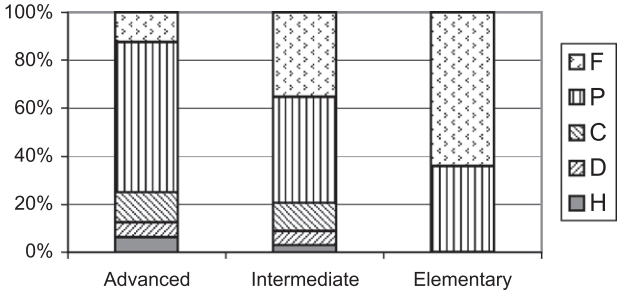

Figure 1. Grades obtained in discrete mathematics.

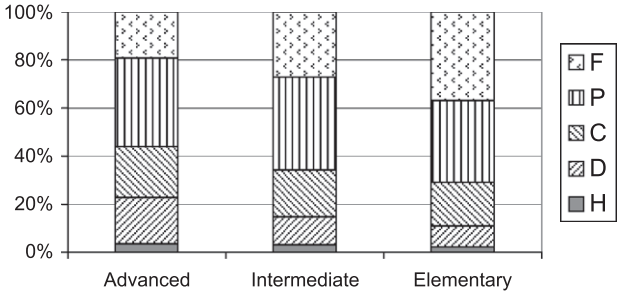

Figure 2. Grades obtained in statistics.

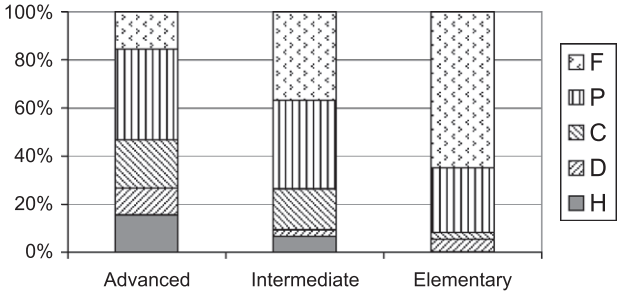

Figure 3. Grades obtained in physics.

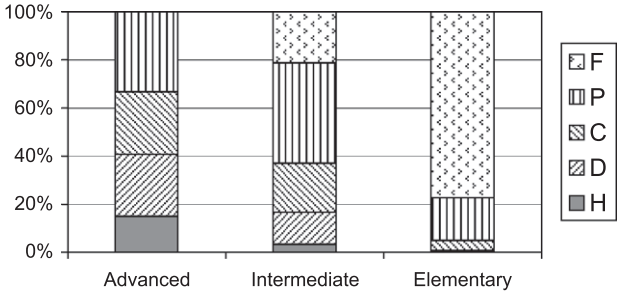

Figure 4. Grades obtained in basic mathematics.

For the basic mathematics subject there **is** a significant positive correlation with the marks in Intermediate (0.60) and Elementary Mathematics (0.49). There is no significant correlation with the marks in Advanced Mathematics.

2.4.1. *The tertiary entrance score*

The significance level used for testing whether or not there is a linear correlation between the UAI and the final marks in each university subject was 0.01.

For the discrete mathematics students and the basic mathematics students there is no significant correlation with the UAI.

For the physics subject there **is** a significant positive linear correlation with the UAI of 0.37 and for the statistics subject there is a significant positive linear correlation of 0.21.

3. Discussion

3.1. *Pass rates*

The difference in pass rates between the three different secondary school mathematics cohorts is striking. The most striking of all are those for the basic mathematics subject shown in Table 2. Every student who studied Advanced Mathematics in secondary school passed and 67% gained a grade higher than a Pass (Table 3). As most of the content of the basic mathematics subject would have been seen previously by the Advanced Mathematics students in secondary school, it is likely that these students are not being challenged by the basic mathematics subject and would have gained more mathematically if they had studied a higher level mathematics subject in first year.

It seems that the basic mathematics subject is not suitable for those who have done Advanced Mathematics. Neither is it appropriate for students who have done Elementary Mathematics. With 77% of these students failing and only 5% achieving more than a 'P', it is clear that the subject is too advanced. The Advanced and Elementary Mathematics students together make up 56% of the basic mathematics students in this study. The subject does not serve this 56% of students well.

For discrete mathematics, physics and basic mathematics, the pass rates of the Advanced cohort was more than twice that of the Elementary cohort. Even in statistics, the difference in pass rates between those two cohorts was an enormous 18%. The proportion of the various secondary school cohorts in a subject could well be the most important factor in pass rates, swamping quality of teaching and other factors.

To improve learning in a subject, it is the Elementary Mathematics cohort who need the most assistance. The Intermediate mathematics students are also in need of assistance as their pass rates would be considered by many to be unacceptable.

The very different pass rates strongly suggest that the tertiary subjects considered in this study are not ideal for many first-year students. Some students could be doing higher level and more challenging work, while others need to start at a lower level. The current subjects sit in an uncomfortable place in the middle and do not serve many students well.

3.2. *Beyond pass rates – performance*

Table 3 gives the percentage of students who gained a grade higher than a 'P' and Figures 1–4 give a graphical view of the proportion of credit 'C' , distinction 'D' and high distinction 'H' grades achieved.

One would hope that the higher levels of school mathematics would not just prepare students to pass a first-year university mathematics subject, but would prepare them to achieve a grade higher than a straight pass, a 'P'. In all subjects considered, those who had done Advanced Mathematics did achieve more 'C', 'D' and 'H' grades than the other students. The difference between the Advanced and the Elementary Mathematics students was considerable in all but statistics.

At the other end, very few Elementary Mathematics students achieved more than a 'P' in physics and basic mathematics, and none achieved more than a 'P' in discrete mathematics.

3.3. *Elementary mathematics for university*

Fewer than one in four students with an Elementary Mathematics background passed Basic Mathematics in this study. This low pass rate raises some concerns:

- Students with secondary school Elementary Mathematics perform very poorly in Basic Mathematics.
- A student who fails Basic Mathematics, and for whom the subject is compulsory, has several options:
  - repeat the subject (perhaps several times),
  - change to a degree requiring less maths, or
  - leave university.

The level of mathematical preparation of students has been shown to have a large impact on performance in this study. The difference between the expected pass rate of the best prepared students and that of the worst is enormous (from 100% to 23% in the Basic Mathematics subject). The pass rates would not be a cause for concern if there were few Elementary Mathematics students and many Advanced students. However, the proportion of Elementary Mathematics students is not small, as can be seen from Table 1.

One of the five key recommendations from the report, [1], on the state of the mathematical sciences includes:

> Encourage greater numbers of high school students to study intermediate and advanced mathematics.

If this recommendation is successfully implemented then the situation will improve. For now we must do what we can with the students we have. The problem of students in engineering, science, computing and health with a poor mathematics background is part of the university landscape these days in many countries.

The intention is not to force students to do a higher level of mathematics beyond their capability. Barrington [10] gives the number of students doing the various levels of mathematics taken by school students in Australia. He shows that over the last few years fewer students are doing the higher levels and more are doing Elementary Mathematics. It is unlikely that a drop in the innate mathematical ability of students is the reason for this change. Anecdotal evidence suggests two possible factors for the

change in levels of mathematics studied at secondary school: secondary school students and their advisors are not aware that higher mathematics is needed for many university degrees, and they perceive that a low level of mathematics results in a higher tertiary entrance score.

Elementary Mathematics clearly does not adequately prepare the vast majority of students for discrete mathematics, physics or basic mathematics. The NSW Board of Studies statement quoted in Section 1.1 states that Elementary Mathematics emphasizes applications of mathematics to finance and data analysis. This emphasis might lead one to believe that Elementary Mathematics would be a good preparation for a first statistics subject; however, it was not the case for students in this study.

Bridging courses are often discussed as a possible solution to poor mathematics preparation. A bridging course is typically an intensive course run for 1 or 2 weeks before students begin their university study. Such courses have several limitations:

- There is little time after students are offered a place at university and before they start classes. Many students have commitments in that time which cannot be altered at short notice.
- Some students do no want to attend extra classes – we are unable to force them to attend.
- One or two weeks of intensive study cannot replace months of secondary school study.

However, bridging courses have been run at UWS and many other Australian universities for many years. The students in this study were informed of the bridging courses available, and strongly encouraged to attend. Having bridging courses has not solved the Mathematics Problem at UWS.

3.4. *UAIs*

The results show that a student's mathematics background is a much better predictor of success in the first-year university mathematically related subjects considered than the tertiary entrance score.

The statistics subject is a little different from the other three subjects considered here in that the level of high school mathematics studied does not have quite as dramatic an influence on the pass rate. The significant positive correlation between marks gained in the statistics subject by the Elementary Mathematics students, and the lack of a significant correlation with Intermediate and Advanced Mathematics marks could be because some data analysis is done in Elementary Mathematics, but not in Intermediate or Advanced Mathematics. The significant positive correlation between the UAI and the statistics marks could reflect both the data analysis content of Elementary Mathematics, and the more general skill base required to do first-year statistics.

4. Conclusion

A student's level of secondary school mathematics is a good indicator of how prepared the student is for university mathematics and mathematics related subjects. It can and should be used to determine, where possible, what mathematics the student does when in first year at university.

Given the above description of General Mathematics it is disappointing to discover that in some first-year mathematics subjects the largest cohort of secondary school leavers have studied General Mathematics. It is not designed for science, engineering or mathematics students; it is shown in this study that it is not an adequate preparation for university mathematics, and the university states very clearly that 2 Unit Mathematics is assumed knowledge for many of its mathematics, science and engineering degrees.

4.1. *The Mathematics Problem*

We do have a Mathematics Problem at UWS.

There are several concerns that follow from the Mathematics Problem. One is that the higher failure rates mean that retention is worse and/or students extend their time at university, with increased cost to themselves and the community.

Another concern is that students with poor mathematical preparation might do what they can to avoid mathematics and statistics subjects during their time at university. Given the recent report from the Australian Academy of Science on the poor state of the Mathematical Sciences in Australia [1], in particular this quote from their key findings

> ... the Australian university system needs to ensure that students from other disciplines, such as economics, education, engineering, and the biological and medical sciences, receive appropriate training in mathematics and statistics.

all that can be done should be to ensure that students get a good mathematics education.

4.2. *Recommendations and a way forward*

Recommendation 1. Recognize that first-year students in mathematics and mathematics-based subjects have different preparation and that these differences have a huge impact on performance in these mathematical subjects.

Recommendation 2. Students who need more mathematics preparation must be provided with extra assistance. A preparatory mathematics subject which is much more substantial than a 1 or 2 week bridging course is needed, and all students who have only Elementary Mathematics as their background should pass it before attempting the standard first-year mathematical subjects.

4.3. *Further work*

We have moved some way to implementing Recommendation 2 at our institution. The preparatory mathematics subject runs as a normal one semester subject. It is suspected that students who have not studied mathematics to HSC level, students who have been away from study for several years, and students who have performed poorly in Intermediate Mathematics would benefit greatly from a preparatory subject. Hence all students who did not complete secondary school mathematics, who did Elementary Mathematics or who performed below a certain

level in Intermediate Mathematics are being asked to sit a diagnostic test. Those who do not reach the required standard will be enrolled in the preparatory subject.

It will be some time before this is completely implemented, and some time after that until the success or otherwise can be measured.

Over half the students in the first-year subjects considered were excluded from this study by the criteria used. These students include:

- Students who did not do all compulsory assessment items. Some may have given up because it was too hard, some may have dropped out but not notified the university. How many of these students lacked confidence or basic mathematical knowledge? How many of these could have been assisted in some way?
- Mature age students, who may have a weak mathematics background, but who have not been included in this study because their HSC results were not available.
- Students who had previously failed the subject and were attempting it again. Did they seek support? How did they perform the second time? Did they eventually succeed or did they drop out?

These groups of students may have their own unique problems which affect their performance in mathematically based subjects. However, knowledge of the mathematics background of students in the groups above will enable staff to put in place strategies to assist such students.

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