# The relationship between breadth of previous academic study and engineering students' performance

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*Abstract*—**Research into indicators that guide the selection of students for admission into Engineering degree programs is important in terms of identifying those students who are most likely to be successful and to tune these indicators to maximise the potential of all students entering universities to study engineering. In this paper we consider the impact that diversity of prior (secondary/high school) academic experience can have on the outcomes achieved by students in engineering degree programs. Whilst there is some research into this aspect in other disciplines, such as health sciences by Shulruf et al [1], this has yet to receive appropriate attention by Engineering. We report on an analysis of the academic performance of approximately 3700 engineering students, comparing their performance in a range of subject areas (including mathematical and science foundations, advanced technical subjects, and broader professionally-focused subjects) and how this performance correlates with the breadth of their previous (secondary school) subject choices and student performances. This breadth is assessed using Schafer's measure of dispersion in categorical data [2] and secondary school subjects are categorized using the New South Wales Board of Studies subject clusters [3]. The results show a significant difference due to the greater dispersion in subject choice for students with different levels of previous academic performance at secondary schools. For students with lower secondary school performance results, an increase in diversity of secondary school subject choices leads to poorer performance in their Engineering degree programs. Conversely, for students with relatively strong secondary school performance results an increase in diversity of secondary school subject choices leads to higher performance in their Engineering degree programs. This may suggest that higher performing students benefit from broader challenges, whereas lower performing students benefit from remaining relatively narrowly focused in their secondary school studies.**

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## I. Introduction

There has been a long history of research into indicators that guide selection of students for admission into undergraduate university level Engineering degree programs, dating back to the 1940's and 1950's [4]–[6]. This research is important given the significant costs associated with educating Engineers, and the potential benefits that can accrue by selecting for admission those students who are most likely to succeed in their Engineering degree program.

Students applying for admission to Engineering degree programs may potentially have very diverse academic backgrounds, prior experience, and socio-economic contexts. Most recent research on relating students' backgrounds to their Engineering degree performance has tended to focus on specific characteristics (such as gender, or previous academic performance). When considering academic performance, the focus has generally been on correlating performance in individually selected secondary school subjects and correlating them to subsequent performance in University programs. There has however been some research in other disciplines, such as, health sciences by Shulruf, Li, McKimm and Smith [1], that rather than exploring single characteristics, has instead considered whether the level of diversity in previous subject exposure is an influencing indicator/factor.

It is reasonable to question whether previous engagement with a more diverse spread of subject choices will lead to higher level performance in an engineering degree (possibly due to an increased ability to draw on wider perspectives) or alternatively lead to lower performance (possibly due to a greater degree of distraction and less focus on developing core technical skills). There are quite diverse beliefs of Engineering academics regarding this issue (typically based on personal experience rather than any rigorous data), and yet there has been limited previous quantitative research to guide these courses of study.

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In this paper we therefore wish to explore whether diverse subject choices and performance at secondary school can be used as an indicator of subsequent performance (either positively or negatively). A data set of ~3700 engineering students (containing both their secondary school and university results) is used to analyse the impacts of prior secondary school subject diversity.

## II. BACKGROUND

There is a substantial body of literature that has investigated predictors of success in University degree programs – both generally and within specific disciplines. Numerous models have been proposed, but possibly the most relevant is work by Tinto [7], which provides a framework for exploring the ability of numerous factors to predict student outcomes. A core component of the model is student commitment or motivation, and from this to self-efficacy.

Despite the value of this work generally, there has been little consideration of its application to Engineering education. The earliest work related to Engineering programs was in the 1940s when Lord, Cowles and Cynamon [5] explored a "Pre-Engineering Inventory" containing "*a battery of seven objective tests, designed primarily to assist in the selection of those students who will be most likely to succeed in engineering schools*". The tests included general and technical verbal abilities, mathematical and spatial abilities, comprehension of scientific materials and mechanical principles, and general understanding of society. The highest correlations as a predictor of success within their engineering program was found to be with general math ability and the lowest was with general verbal abilities and spatial visualisation, though there was significant variation across different programs and a weighted combination across multiple tests generally performance much better. Similar outcomes were also found (or hypothesised) in other (narrower) studies during this period [4], [6].

There is only limited research within the Engineering Education literature over the following 50 years, though there was a resurgence of interest in the field around 2000 [8]–[11], with a growth in the range of potential indicators being explored, such as gender and psychosocial variables. More recently Lowe and Johnston [12] studied the correlation between students' undergraduate performance and student responses to their motivation and aptitude prior to commencing their University studies. Knipe [13] also considered whether the students' Australian Tertiary Admissions Rank (ATAR[1]) could be used to predict the likelihood of students successfully completing degree programs. More recently Lowe, Wilkinson & Johnston [14] analysed a large data set of university entry scores and compared them with yearly average marks in engineering degree programs in order to investigate correlations between specific subject choices made at high school and their university level engineering degree performances. Wurf and Croft-Piggin [15] consider the Australian Tertiary Admission Rank (ATAR) as well as a range of other measures. The result of these studies has generally been to identify statistically significant correlations between individual student characteristics and subsequent undergraduate degree performance. Studies such as these have then been used to develop or adapt selection criteria or tests for entry into Engineering programs, such as the Graduate Aptitude Test in Engineering (GATE) used by many Universities in India. Other institutions (such as NUS in Singapore) have developed tests that assess the students' broader affinity with Engineering and general aptitude - but these correlations appear uncertain given the size of the data set.

Other studies, such as work by Scott and Yates [16] rather than considering undergraduate academic performance have tracked students through into graduate roles and explored characteristics of those graduates who are deemed to be 'highly successful' by their employers, though this generally had been in in terms of personal traits rather than clear academic performance measures.

What all these studies have generally failed to consider is the interplay between different characteristics. For example, whilst academic performance in a range of general secondary school subject areas might only be individually weakly correlated with subsequent engineering degree performance, it is worth considering the possibility that taken together there is a stronger correlation – i.e. the possibility that there might be a correlation between students studying a wider range of subjects in secondary school and their performance in their engineering degree program. The potential for this association is alluded to by the performance of students undertaking combined degree programs at the authors' home institution – The University of Sydney – slightly more than 50 percent of commencing domestic undergraduate Engineering students are enrolled in a combined degree program involving a Bachelor of Engineering as well as a second degree in Arts, Commerce, Science, Architecture or other programs. There has long been an anecdotal belief that these combined degree students outperform the single degree Engineering students. A simple analysis shows that over the period 2006-2016, the combined degree students had an average course mark that was 6.13 marks higher than the single-degree students (though it is worthwhile noting that that combined degree programs did attract students who had previous results that were higher). A pertinent question arising from these observations is whether more academically capable students are attracted to a wider range of subject choices at high school and whether students who undertake a wider range of subject choice develop an ability to perform at a higher level at university.

This question has not been explored within the Engineering context and only limited consideration has been found for other disciplines. Shulruf, Li, McKimm and Smith [1] considered the connection between breadth of knowledge and grades for students studying health sciences at a large NZ University. Interestingly, they found that breadth of knowledge (as measured by the number of units undertaken at Secondary school) made little difference in terms of achievement in three undergraduate health profession programmes, though the analysis was at a relatively macro level.

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[1] The ATAR is an Australian academic ranking measure expressed as a value between 0 and 100, and which indicates the nominal position of high school students within the total theoretical cohort of students who could have undertaken the Higher School Certificate within their year. The ATAR is typically used as the primary basis for entry to University courses.

In this paper we aim to address the gap in knowledge and explore whether a relatively strong correlations can be established with a relatively large cohort of Engineering students.

## III. Methodology

In this paper an analysis is presented of the academic performance of a large cohort (N=3720) of undergraduate students who undertook Engineering degree studies at The University of Sydney between 2006 and 2016, and who had previously undertaken the NSW Higher School Certificate (and for whom we therefore have detailed secondary school results). The data does not look at a particular year cohort, but rather all students who were enrolled in any individual unit of study[2] over the time period being studied.

The cohort is relatively evenly split between students enrolled in a single 4-year Engineering degree (N=1908) and those enrolled in a combined degree (N=1812) that combine their Engineering degree with a second degree (typically Science, Arts, Commerce, Architecture or Law). The students are spread across a range of Engineering disciplines including Civil (~33%), Aeronautical (~18%), Mechanical (~10%), Biomedical (~9%), Chemical (~9%), Mechatronic (~8%), Electrical (~8%), and Software (~4%). For each student we have data on:

- The students' overall high school ATAR.
- The subjects undertaken in the NSW Higher School Certificate (the secondary school qualifications within NSW) and the results in each subject.
- The engineering course in which the student was enrolled.
- The results in every course attempted within their degree program.

For the purposes of considering performance within the students' engineering degree program we have calculated a number of different performance indicators:

- WAM (Weighted Average Mark) for all attempts at all courses undertaken in their degree program (the units are weighted by the credit point value).
- WAM Year1: during the first year of their degree program.
- WAM Maths: for all Mathematics courses.
- WAM Discipline: for all technical discipline-focused courses.
- WAM Engineering: for all broad professional engineering units.

The consideration of the breadth of previous secondary school studies is complicated as the NSW Secondary School Students have a choice of several hundred different courses. These courses do however fall into a much smaller set of categories, as defined by the NSW Education Standards Authority. Specifically, the courses can be grouped into eight main categories as follows:

- English.
- Mathematics.
- Science.
- Human Society and Its Environment.
- Personal Development, Health and Physical Education (PDHPE).
- Technology.
- Languages.
- Life Skills Courses.

We are therefore able to group students HSC courses into these categories and then calculate a measure of dispersion amongst these categories. We have used the dispersion measure defined by Schafer [2]:

$$D = k/(k-1) \,.\, [1 - (\sum N_i^2)/N^2] \qquad (1)$$

Where:

- D = Dispersion
- k = the number of categories
- N = the number of observations
- $N_i$ = the number of observations in the *i*th category

Dispersion is minimal when all the observations are in a single category (and so $N_i$=N for that category, and $N_i$=0 for all other categories, giving D=0). Conversely, maximum dispersion is conversely achieved when the observations are spread as evenly as possibly across the categories (i.e. $N_i$=N/k, giving D=1).

For the purposes of our analysis we define 3 different sets of categories, resulting in three different dispersion measures:

- D1: Treating all eight categories separately (i.e. k=8).
- D2: Combining Mathematics, Science and Technology into a single category (i.e. k=6). Engineering degree programs typically attract students who have an inherent interest in STEM (Science, Technology, Engineering and Mathematics) fields, and so it is very common for students to take subjects in these fields, whereas choices regarding subjects from other areas are much more variable.
- D3: Combining English with Mathematics, Science and Technology (i.e. k=5). Following from D2, it is also worth noting that in the NSW higher school certificate, English is mandatory, and as such all students will undertake English at some level.

We then explored the effects on overall student performance and the relationships between Dispersion, ATAR and WAM.

[2] At The University of Sydney, the overall degree program in which the student enrols is referred to as a "Course", whereas the individual blocks in which they enrol each semester are referred to Units of Study.

## IV. Results and Analysis

### A. *Choice of Dispersion Measure*

In order to assess the relevance of the difference dispersion measures we calculated the Pearson correlation between the Engineering degree subject results (WAM) and the three dispersion measures D1, D2 and D3. The relationship for D1 is shown in Figure 1. The associated correlations are:

- WAM – D1 : r = 0.058
- WAM – D2 : r = -0.108
- WAM – D3 : r = -0.102

This suggests that D2 and D3 will have better predictive power than D1. This is likely to be due to the additional variation in the dispersion arising from students undertaking subjects across the three categories of mathematics, science and technology. Whilst D2 has a marginally higher correlation with WAM than D3, we have chosen to use D3 for subsequent analyses as a visual inspection of the scatterplot shows significantly fewer outliers for D3.

### B. *Impact of Dispersion on Different Subject Types*

The correlation results illustrated in Figure 2 suggest that there is, on average, a decline in engineering degree performance as dispersion D3 increases – reducing from a mean WAM of 65.0 at a dispersion of <0.2, to a mean WAM of 56.5 at a dispersion of 0.8 to 0.9. In other words, this seems to imply that Engineering students who undertook a narrower (more technically-focused) set of subjects for the HSC typically performed better within their Engineering degree program.

It is worth noting that this decrease in University performance results for increasing dispersion occurs for all types of University subjects. To assess this we considered the different WAM measures. These results show that the pattern of declining University performance for increasing dispersion is broadly consistent across WAM measures – i.e. increasing dispersion does not seem to impact on performance in first year, technical, mathematical or general professional subjects.

The one exception is an increase in performance for general professional subjects for students with very high levels of secondary school subject dispersion – though this may well be a statistical anomaly, as only 20 students have this very high level of dispersion (for reference, consider two example students at this extreme end of the dispersion scale: one undertook Advanced English, Mathematics, Modern History, Studies of Religion, Italian, and Visual Arts. The second undertook Advanced English, Mathematics, Physics, Economics, PDHPE, and Italian).

### C. *Impact of Dispersion for Single and Combined Degree Students*

At this stage it appears that, for Engineering students, there is little to be gained from studying a greater diversity of subjects at secondary school (at least in terms of impact on the performance in their Engineering degree, though there might well be wider benefits). It is worth exploring whether this is equally the case for both single and combined degree students. It might be hypothesised that students undertaking combined degree might inherently have a wider range of interests, and hence benefit from the stimulation arising from a more diverse range of secondary school subjects.

The results of a comparison of students undertaking single Engineering degrees versus an Engineering degree combined with another undergraduate degree is shown in Figure 3. As noted earlier, the average performance of the combined degree

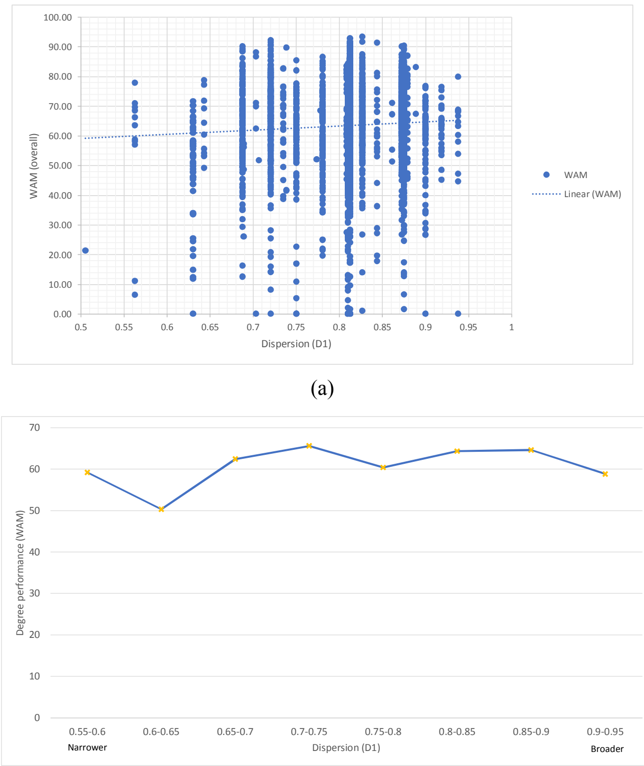


Fig. 1. HSC subject dispersion (D1) versus Engineering performance (WAM) (a) scatter graph for all students (b) mean across students in each dispersion band.

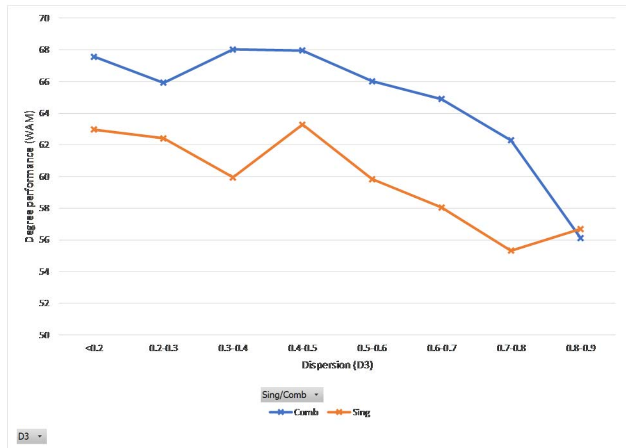


Fig. 2. HSC subject dispersion (D3) versus Engineering performance (WAM) – comparing Single and Combined degree students.

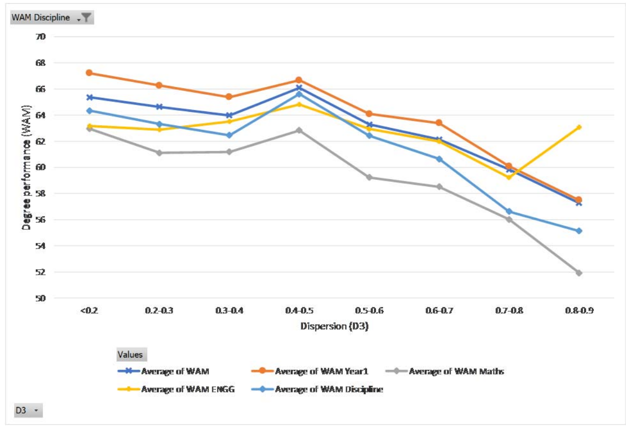


Fig. 3. HSC subject dispersion (D3) versus Engineering performance (WAM) – comparing different WAM measures.

students is generally higher than the single degree students (a previous analysis, not reported here, had shown that this was a consequence of higher achieving students self-selecting into combined degrees rather than a consequence of the degree programs themselves).

Whilst the results do appear to show a somewhat surprisingly greater decline in mean performance against increasing dispersion for combined degree students than for single degree students. This is however likely to be a consequence of the small data sample at the very high dispersion level. Considering the dispersion bands where we have N>100, increasing dispersion from <0.2 to 0.7-0.8 results in a drop in mean WAM of 7.64 for single degree students, and 5.27 for combined degree students.

### D. *Impact of Increasing Dispersion for High-Achieving vs Lower-Achieving Students*

Up to this point in the analysis, we have been looking at the impacts of greater dispersion in secondary school subject choice independently of the students underlying academic performance. If we treat the students' ATAR as an indicator of the student previous overall academic performance then we can explore the relationship between secondary school subject dispersion (D3) and engineering course performance (WAM) for different ATAR bands.

The result of this comparison is shown in Figure 4. This Figure highlights several interesting outcomes. As would be intuitively expected, students with a higher ATAR generally perform better in their engineering program (e.g. students with an ATAR in the 95-100 band on average achieve a WAM ~8 points higher than students in the 90-95 ATAR band.

More interestingly, this figure shows that whilst the negative correlation between secondary school subject dispersion and engineering course performance that had been evident in the previous analyses holds true for lower ATAR students, for those student with a relatively high ATAR (i.e. >90, and particularly >95) this pattern reverses - i.e. for students with high ATARs, having a very high level of secondary school subject dispersion is correlated to a higher level of engineering course performance. As explained earlier, the data at the high dispersion levels above 0.8 is sparse and statistically unclear however these trends are noted in the range of data between 0.5 and 0.8 where it is statistically relevant.

This pattern is somewhat surprising and potentially unexpected, at least insofar as such a pattern has not previously been reported in the literature. Our current data does not however

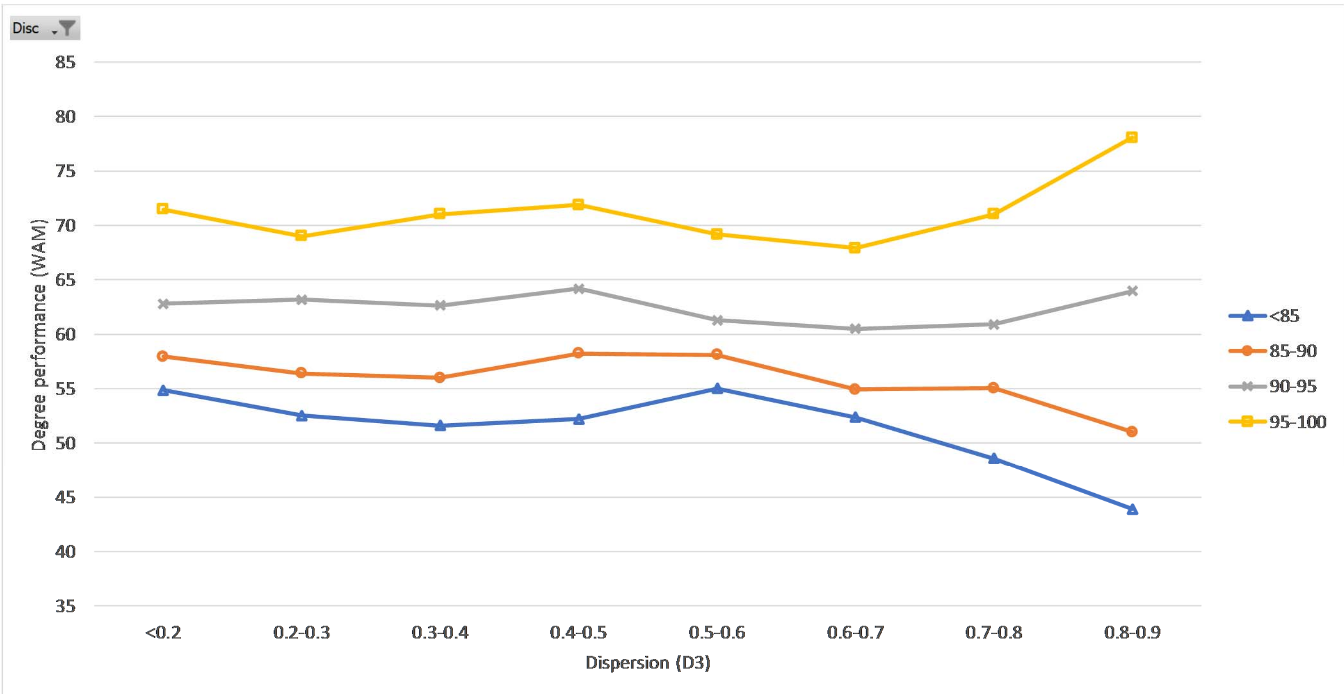


Fig. 4. HSC subject dispersion (D3) versus Engineering performance (WAM) for different ATAR bands.

allow an exploration of whether there is a causal relationship at play. We can however consider both possible causes and potential implications of this finding.

## V. Discussion

It could be hypothesised that less academically accomplished students (i.e. those typically with lower ATARs) benefit in their engineering program from a clear focus. For these students undertaking a wider range of secondary school subjects may lead to weaker preparation in the fundamentals needed for success in their Engineering degree and/or provide a distraction within their degree.

Conversely, more academically accomplished students (i.e. those typically with higher ATARs) are more likely to have sufficient mastery of the fundamentals, and hence a wider range of secondary school subjects provides them with a breadth of perspectives which they can draw upon in enhancing their engineering results. At this stage this is however just speculation. This finding does however warrant further exploration.

If validated, this finding is quite significant in several ways. Firstly, it has implications for the advice that might be given to students interested in an Engineering program regarding their secondary school preparation, and the circumstances under which they may wish to study a broader or narrower range of subjects. Secondly, and possibly more importantly, it raises questions regarding the design of Engineering curricula and why it may, or may not, allow students to leverage a breadth of previous study.

Whilst utilising a relatively large data sample, this research still has a number of limitations. The most substantial of these is that the data was associated with students studying Engineering in a single institution, and therefore a particular curricula design. An important future step would be to research whether the same patterns occurred in other Engineering programs.

There are also a number of other questions that would also be worth exploring in future research. Examples include: are there gender or socio-economic differences in the patterns that have been identified? Is there a difference in subsequent career choices or trajectories for those students with higher subject dispersion? Are there differences in the identified patterns between the different engineering disciplines (e.g. are the patterns different between mechanical, civil, electrical or software engineering)?

## VI. Conclusions

Diversity of curriculum has become an important feature in developing the required attributes of secondary/high students and this aspect is now shown to have an impact on their successful university level engineering studies. The diversity of studies at secondary school appears to not only have an impact on the choices that students make in undergraduate engineering programs but also has an impact on the performance of all undergraduate non-engineering students.

The construction of indicators to characterise the diversity or dispersion of studies in secondary schools deserves attention and three dispersion indicators are presented and shown to have relevance in different circumstances.

Students with relatively strong secondary school performance (characterised as high ATARs) and high diversity of secondary school studies perform well at university whereas weaker students are better to have relatively narrower curriculum at secondary school.

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