Factors affecting success in CHEM101 at UOW

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Abstract

In 2010 the Faculty of Science at the University of Wollongong (UOW) decided to inform its admissions policy by analysing the results in the introductory chemistry subject CHEM101. The data was analysed by members of the School of Mathematics and Applied Statistics using a generalised linear model. This paper discusses the model and its implications. One of the conclusions is that the level of mathematics studied for the Higher School Certificate (HSC) is a better predictor of performance in CHEM101 than either the HSC Chemistry mark or the student's Australian Tertiary Admission Rank. As a result of the analysis in this article, the Faculty of Science at UOW changed its early admission procedures. A pdf file of a presentation by the first author on this material and an interactive passing probability calculator based on the model are available at [11] and [10] respectively.

1. Introduction

Admission of Australian high-school students to universities is typically based on their performance as measured by a single number called the Australian Tertiary Admission Rank (ATAR). It is calculated on a state-by-state basis using a statistical analysis of the performance of all the students in the state across all their subjects [1]. Our analysis involved students whose ATAR was calculated in the state of New South Wales (NSW) on the basis of their performance in the Higher School Certificate (HSC).

The only compulsory subject in the NSW HSC is English, and you can't tell by looking at a student's ATAR whether they have studied mathematics. Universities in Australia typically have few prerequisites as a barrier to entry. This is a matter for some consternation, and recommendation 12 in [2] is that government

> urge universities to send accurate signals about the value of mathematics, engineering and science to schools, students, teachers and careers advisors.

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Some universities encourage students to take appropriate subjects at high school by increasing the ATAR of students who achieve various levels of performance in relevant subjects at high school. Schemes such as these typically reward students for taking subjects that are considered relevant by the Faculty making the decisions, rather than on an analysis of the impact on performance of studying the subjects.

We analysed the performance of students at UOW in CHEM101 (Chemistry 1A: Introductory Physical and General Chemistry) in the Autumn session of 2010. CHEM101 was chosen because it is a key enabling science subject that is compulsory in many majors in a Bachelor of Science (BSc) and in other degree programs. Some analyses have been done on the impact of mathematical background on the performance of students at other institutions [5], [9], [13]. All conclude that increased mathematical competencies result in improved success at university. Our results would support this conclusion as well as results specific to chemistry [3], [6], [4]. In particular, our results support research [4] concluding that mathematical difficulties experienced by chemistry students were more likely to be a result of insufficient understanding of mathematics rather than an inability to use their mathematical knowledge in a chemical context.

We develop a generalised linear model of the data which enables us to test quite specific scenarios. While one always has to be careful when extrapolating data, the sample size is reasonable (383 students) and the conclusions are striking.

The model produced enables the calculation of the probability of a student with a given background (in terms of the variables considered) passing CHEM101. Our calculations indicate that the single variable with the strongest positive correlation to passing CHEM101 is the high-school mathematics result. This is followed by the high-school chemistry result, and then the ATAR.

In order to give a more detailed summary of the implications of the model we first describe the variables considered. Four levels of mathematics are available to students undertaking the HSC in NSW. In order of mathematical sophistication, they are: General Mathematics, Mathematics, Mathematics Extension 1, and Mathematics Extension 2. Students taking Mathematics Extension 2 must also take Mathematics Extension 1. Students taking Mathematics Extension 1 but not Mathematics Extension 2 must also take the Mathematics course. Mathematics can be taken on its own, and General Mathematics cannot be taken in conjunction with any of the other mathematics subjects. There is only one chemistry subject available to HSC students, namely Chemistry. Students who did not study Chemistry but wish to enrol in scientific degrees at UOW have the option of taking a chemistry summer bridging course. The chemistry bridging course is encouraged but not compulsory.

Our model suggests that students entering the Faculty of Science having not done Chemistry at high school and not having undertaken a chemistry bridging course need to have a score of over 85 in General Mathematics if they are to have probability of at least 50% of passing CHEM101. In contrast, students with the same profile in terms of the non-mathematical variables who undertake higher levels of mathematics at high school are almost certain to pass CHEM101.

The analysis gives insight into which factors most influence performance, enabling informed policy decisions to be made regarding admission into subjects and degree programs. Our results were so striking in the context of students at UOW that immediate action was taken; Early Entry to the Faculty of Science was only considered for students studying Mathematics or Mathematics Extension subjects at high school.

Careers Advisors often advise students to undertake lower levels of mathematics in the expectation that they will perform better, and in the hope that this performance will result in a higher ATAR. This is often, unfortunately, reinforced by teachers [7]. Our results indicate that advising students to undertake lower levels of mathematics at high school is essentially encouraging them to mortgage their future.

2. The data set and the construction of the model

2.1. The data set

The data set consists of 383 domestic undergraduate students who studied CHEM-101 in Autumn session 2010 at UOW, having completed the HSC in 2009 or earlier. The data available for each student includes: ATAR; HSC year; university degree and faculty; flags indicating whether or not the student studied HSC Chemistry, completed a UOW chemistry bridging course, or took part in Peer Assisted Study Sessions (PASS) for CHEM101; the student's HSC Chemistry mark (if applicable); the level of HSC mathematics studied; the student's HSC Mathematics mark and Mathematics Extension mark (if applicable), and the student's CHEM101 final mark and grade.

For the purposes of our analysis, we worked with a dichotomous Pass/Fail variable; any mark less than 50 in CHEM101 was considered a Fail, and any mark greater than or equal to 50 was considered a Pass. The average ATAR of the students who failed CHEM101 in 2010 was approximately 74, and 17 of the 383 students had not done any mathematics at the HSC.

2.2. The model

We built a logistic regression model using the forward selection approach to stepwise regression. The outcome of interest is a Pass grade for CHEM101. The stepwise regression was conducted using the statistical programming language R, with ANOVA F-tests used to test predictors for statistical significance. In the forward selection method, predictors are considered separately before interactions are analysed. However, Mathematics and Chemistry marks are only meaningful for students who studied those subjects, and hence these variables were only ever considered for inclusion as interaction terms. We refer the reader to [8] for further general information on the formation of the logistic regression model.

In the first stage, the interaction term consisting of HSC mathematics marks and the level of mathematics studied was found to be the most important factor. ANOVA tables were then generated comparing this fit to potential new models (each consisting of the HSC mathematics interactive term and one other factor), and the process was repeated, resulting in the interaction term for HSC Chemistry being added to the model. The forward selection process was continued in this way until it was found that the factor associated with the greatest deviance was not statistically significant. Several new interaction variables were then tested for significance, and an interaction term linking the chemistry bridging course flag and the CHEM101 PASS flag was added to the model although, independently, neither of these variables was found to be significant.

The following factors, listed in order of significance, are included in our final model: Interaction variable — HSC mathematics marks and level of mathematics studied; Interaction variable — HSC Chemistry marks and HSC Chemistry flag; ATAR; Faculty; HSC Year; Degree; Interaction variable — chemistry bridging course flag and CHEM101 PASS flag. The statistical significance drops markedly after the first three.

Rather than describe the model in numerical detail, we have posted an interactive scenario-builder on the UOW website at [10].

3. Observations and scenarios

The model may be used to estimate the probability of a student passing CHEM101 given specific values for each of the predictor variables, irrespective of whether an actual student had that particular profile in 2010. The relative significance of the variables is also noteworthy. We emphasise that care must be taken when using the model as extrapolation from the data must be done carefully. This is particularly true of smaller cohorts such as those who studied no mathematics at HSC (only 17 people) and those who were in small degree cohorts. The largest single cohort of students was those enrolled in a BSc in the Faculty of Science who did the HSC in 2009; this is therefore the safest baseline assumption.

3.1. Impact of level of mathematics studied

The level of mathematics studied for the HSC and the HSC mathematics mark are a better predictor of performance in CHEM101 than either the HSC Chemistry mark or the ATAR.

Scenario 3.1. Suppose Hermione completed the HSC in 2009, received an ATAR of 74, and enrolled in a BSc at UOW. Suppose also that she did not study HSC Chemistry, did not attend the chemistry bridging course, and did not participate in PASS for CHEM101. What mark would she need to have in her HSC mathematics subject in order to have a greater than 50% chance of passing CHEM101? If she studied General Mathematics then her mark would need to be at least 87. In contrast, if she studied Mathematics, then only a mark of at least 19 would be required.

Thus, according to our model, the two scenarios summarised in the table below are equivalent for the purposes of passing CHEM101.

Maths type	Maths mark	Chemistry mark	ATAR	Bridging/PASS
General Maths	87	–	74	–
Mathematics	19	–	74	–

No students in CHEM101 had a score below 49 in Mathematics, so the second of these scenarios is extrapolating far from the original data and should be interpreted with caution. However, it suggests that even a borderline performance in Mathematics is more advantageous than a strong performance in General Mathematics. In fact, 92.8% of Mathematics students in the data set passed CHEM101, as did 94.7% of Mathematics Extension 1 or 2 students, whereas only 62.5% of General Mathematics students passed CHEM101. It seems to be a matter of content rather than performance.

Students who take General Mathematics rather than a higher level of mathematics at school are mortgaging their future.

3.2. Relative impact of HSC mathematics and chemistry marks versus ATAR

Scenario 3.2. Suppose that two students, Harry and Ron, completed the HSC in 2009, enrolled in a BSc at UOW, and neither student completed the chemistry bridging course or participated in PASS for CHEM101. Suppose further that Harry received an ATAR of 90 and did not study Chemistry or any level of mathematics for the HSC whereas Ron received an ATAR of 50 but studied both Chemistry and Mathematics, receiving marks of 78 and 52, respectively. According to the model, both Harry and Ron have approximately an 80% chance of passing CHEM101.

The BSc degree typically has an ATAR cut-off of 75 at UOW, meaning that Harry would be admitted into the degree, but Ron would not. The model suggests that both students are equally likely to pass CHEM101.

Scenario 3.3. If Ron, like Harry, had not studied chemistry or mathematics for the HSC, his chance of passing CHEM101 would have only been approximately 10%. Alternatively, if it had been General Mathematics rather than Mathematics for which Ron had received a mark of 52, his chance of passing CHEM101 would have been approximately 11%. Even though he did not receive high marks for Chemistry or Mathematics, the probability of Ron passing CHEM101 was significantly improved by the fact that he studied these subjects.

It is tempting to conclude that the ATAR alone is a poor criterion on which to base admission to the BSc. In reality, of course, a student's ATAR is dependent on their performance in their HSC subjects. Given a score of 78 in Chemistry and a score of 52 in Mathematics, Ron would have to perform very weakly indeed on his remaining HSC subjects in order to receive an ATAR of 50. In any case, it would seem that the trend to award extra ATAR points for the study of degree-specific subjects at high school is justified. Moreover, prospective science students should be awarded bonus ATAR points for studying higher levels of HSC mathematics as well as HSC Chemistry.

3.3. The (in)significance of the Faculty and Degree variables

One could hope that students in certain Faculties/degrees are more motivated to do well in chemistry. There is some evidence for this as students who did General Mathematics were more likely to pass CHEM101 if they were general science students than if they were engineers or physicists, despite the fact that the BEng has a higher ATAR cut-off than the BSc. However, both Faculty and degree paled into insignificance for students with higher levels of HSC mathematics.

3.4. The effect of gap years

Some of the students had done the HSC in 2009, some in 2008, and some earlier. Of those who did the HSC in 2008, most studied CHEM101 in 2010 because they had not started university studies until 2010, although some took CHEM101 in their second year of university studies. We do not distinguish between these two cohorts and refer to both as *gap year* students.

Scenario 3.4. Suppose Sally scored 78 in Chemistry, 52 in General Mathematics, received an ATAR of 74, and did not participate in PASS. If she had done the HSC in 2009 the probability of her passing CHEM101 in 2010 would have been just under 50%. If instead she had done her HSC in 2008 (and received a UAI rather than an ATAR), she would have the same chance of passing CHEM101 as Harry and Ron in Scenario 3.2, namely 80%.

Generally, gap-year students were more likely to pass CHEM101 than students with comparable backgrounds who took CHEM101 the year after finishing high school. This may be influenced by the change in methodology from the calculation of a Universities Admission Index (UAI) in 2008 to an ATAR in 2009.

Scenario 3.5. In Scenario 3.1 we saw that Hermione needed a score of 87 in General Mathematics to have at least a 50% chance of passing CHEM101 having done her HSC in 2009. If all other factors remained unchanged except that she did her HSC in 2008, she would only need a score of 69 in General Mathematics to have at least a 50% chance of passing CHEM101. This still compares poorly with the score of 19 required in Mathematics if she sat the HSC in 2009.

The gap-year advantage did not outweigh mathematical advantage; gap-year students were less likely to pass CHEM101 than students who took higher levels of mathematics in their HSC in 2009. The level of mathematics students undertake at high school has a significant impact on university performance for at least two years after leaving high school, even if they undertake a year of university study.

3.5. HSC Chemistry, chemistry bridging courses, and concurrent support

The statistical significance of participating in the chemistry bridging course is low compared to the significance of studying HSC Chemistry. Chemistry bridging courses are no substitute for HSC Chemistry; keeping up is more beneficial than catching up.

The lack of statistical significance of both the chemistry bridging course and the CHEM101 PASS program independently but the statistical significance of the interaction variable between them is noteworthy. Our interpretation is that remedial support for students with a weak chemistry background should take the form of intense preparation prior to session combined with ongoing support throughout session. Each type of support is on its own insufficient to ensure success but the combination is mildly beneficial.

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