An evidence-based predictive tool for motivating engagement, completion, and success in freshmen engineering students

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***Abstract**: In general, teachers deploy several methods to encourage their students to engage early with their learning during their course of study. These methods include: presentation of previous years' pass/fail rates; feedback from previous students; and anecdotal evidence suggesting that active engagement, punctuality in attending lectures, and good performance in interim assessments will contribute to success. We postulate that engineering students will be more inclined to improve their behaviour if they are provided with quantitative evidence that adopting certain behaviours will enhance success and improve course grades. Furthermore, we postulate that students will embrace a conceptual and logical tool that allows them to take control of the course outcome they seek. A tool based on these principles has already been accepted and used enthusiastically by some students in another department at Unitec(Mellalieu, 2011). Inspired by the success of this approach, we have conducted a data mining analysis of previous students' class attendance and assessment performance records to develop a similar tool for a freshman course within an undergraduate engineering programme at the same institution. The model underpinning the tool demonstrates empirically that better attendance in lectures and higher performance in interim summative assessments are associated with higher final examination results. Furthermore, the tool enables the lecturer to achieve early detection of 'at risk' and struggling students who may not achieve successful course completion without a significant intervention by the teacher, and/or change in behaviour by the student. At Unitec, a conscious effort is made to attract to engineering education students from communities whose participation hitherto has been low. Identifying and following up those who may be experiencing difficulties is crucial for their retention and maintaining diversity. All New Zealand tertiary institutes are now increasing their focus on successful completions (outputs) rather than the number of enrolments (inputs). The tool described is one useful approach to providing necessary and timely additional support to students at risk of failing to complete.*

Introduction

Tertiary institutes are focussing increased attention on identifying which students are likely to succeed - or fail - in their tertiary studies. Historically, academics have been keen to identify the 'bright young things' they view as prospects for recruiting to postgraduate courses. Less attention has been paid to those students who fall by the wayside since there have been plenty of ambitious and talented students to take their place. More recently, institutions have been obliged to pay attention to identifying those students 'at risk' of failure and conducting remedial interventions. For instance, Culver (Culver, 2011a, 2011b) reports on the services provided by the Noel-Levitz consultancy for improving institutional retention in North America. He argues that the business case for active and early management of student retention is compelling.

New Zealand tertiary institutes are beginning to use approaches for success and retention similar to

those adopted by North American institutions. The driver for the New Zealand initiative is that government funding for higher education is being redirected towards a focus on outputs (such as course completions) rather than inputs (student enrolments); government funding is given to completions of academic programmes rather than simply student enrolments (MoE, 2010). It is noteworthy that in New Zealand about one-half of tertiary education funding is allocated through grants and loans to students, and institutional funding. Concurrently, another policy focus has been to recruit students from non-traditional demographic sectors into higher education. Furthermore, there are also significant funds and support made available for students from non-traditional backgrounds but with matching expectations to succeed.

Unitec is a tertiary education institute with a specific mandate for trades training, technology-based undergraduate degrees and diplomas. In the Department of Civil Engineering, first year courses such as Mathematics and Fluid Mechanics that rely on proficient numeracy skills experience relatively higher failure and dropout rates ranging from 40-50%. Several factors are presumed to contribute to this lack of success:

- The need for teaching delivery efficiencies has led to larger combined classes of students enrolled in different programmes with diverse prior learning experiences and learning capabilities;
- New Zealand's increasing need for engineers and engineering technologists in the medium to long term future has compelled tertiary institutes to encourage participation of students from under-represented demographics who are still adapting to the challenges of studying the 'new' study areas; and
- An apparent decrease in the numeracy and literacy skills of new entrants. For instance, a recent study reports that around 40% of adult New Zealanders have literacy and numeracy skills "below a level needed to use and understand the increasingly difficult texts and tasks that characterise a knowledge society and information economy" as stated by Coolbear and Schöllmann (Whatman, Potter, & Boyd, 2011).

Several years' experience teaching Fluid Mechanics to first year students suggested anecdotally an association between students' attendance in lectures, participation in class exercises, performance in intermediate assessments, and their final achievements in the examination. Consequently, several methods were deployed to convince and motivate each new student cohort of the benefits of early engagement to their learning. These methods included: presentation of previous years' pass/fail rates; feedback from previous students; and anecdotal evidence suggesting that active engagement, punctuality in attending lectures, and good performance in interim assessments would all contribute to success.

However, we suspect that engineering students might be more inclined to adopt success oriented behaviour if they are provided with quantitative evidence that their behavioural change can lead to success and improved course grades. Furthermore, students may embrace a conceptual and logical tool that allows them to take control of the course outcome they seek. A tool based on these principles has already been accepted and used enthusiastically by some students in the Business School of Unitec (Mellalieu, 2011). As a preliminary step to building such a tool, this paper identifies and establishes explicit, quantitative patterns between student behaviour and the outcomes achieved. Next, how a tool might be presented to students studying Fluid Mechanics is illustrated. Finally, how the tool developed could be extended to include additional data to provide early warning of 'at risk' students is presented. The benefits of the tool, not only to the lecturer, and the students but also to the management are discussed. As stated by Ambrose et. al. ((2010)) when considering ways that our students' goals influence their learning behaviours it should be born in mind that students' goals for themselves may differ from our goals for them.

Method

This study drew on data collected for a total of 56 students enrolled in Fluid Mechanics in 2010. The data included, for each student, the enrolled programme, attendance in 10 lectures, marks for three summative assessments (counted as coursework), and a mark for the final examination. Table 1 below presents the characteristics of the programmes, number of lectures and tutorials (on left), and assessments (on right).

Table 1: Characteristics of the programme

	Number
Diploma students (DIP)	30
BEngTech Degree students (DEG)	26
Total students	56
Lectures & tutorials (L1, L2,L3, etc)	10

Assessment	Nature	Course weight
Assignment	Open book	15
Test	Closed book	20
Lab Report	Open book	15
Examination	Closed book	50

The analysis sought answers to questions of value to the lecturer, students and institute's management:

1. Is the attendance in lectures in the early stages critical to the examination outcome? If affirmative then it provides one good early indicator for the lecturer to identify at-risk students.
2. Is overall attendance in lectures critical to the examination outcome? If affirmative then it provides evidence-based quantifiable proof and a tool for student motivation.
3. Do students in different programmes perform differently? If affirmative then it suggests that the differences in prior learning in the two programmes play a significant role and further reflection is needed before management combines these two groups in the future.
4. Is attendance of students who have more advanced prior learning important to success? If positive then it further confirms (2) above and can be a motivational outcome for students.
5. Is the performance in early open book uncontrolled assessment (the first assessment) indicative of the performance at the final examination? If affirmative this gives the lecturer a second opportunity to identify at-risk students fairly early in the semester. The outcome is valuable for the lecturer as well as managers to put in place supportive mechanisms.
6. Is the performance in the Test (closed book) indicative of the performance at the final examination? If affirmative, it confirms the view that the outcome of a closed book assignment is a good judge of the result likely from an examination, a useful information for the lecturer and management.
7. Do the data suggest a revival in student performance following a closed book assessment event? If affirmative, for lecturers it confirms the need for at least one closed book event in the coursework component that provides a simulation of examination conditions. For students it provides an opportunity to appreciate the need for adequate preparation for an examination.

An exploratory data analysis approach was used to identify and explore the foregoing hypotheses using the WEKA® data mining workbench software (Bouckaert et al., 2010; Hall et al., 2009; UoW(MachineLearningGroup), 2011). The exercise included uploading the relevant data from the sample of 56 students and eliciting models that 'best' represented the relationship between the inputs (contributing factors) and output (exam mark). In this context, the 'best' models were chosen on the basis of parsimony in the number of variables used and statistical measures (such as standard error). Using the identified relationships, a specific predictive decision support tool assembled in the form of a series of Microsoft Excel® spread sheets was developed to be used by the lecturer, students and management.

Results

The results obtained from the data mining process and the elements of the predictive tool developed using those results are presented below in relation to the questions above. The predictive tool was a simple, easy to use Excel workbook containing worksheets for each predictive component.

Attendance in lectures (Early Detection worksheet)

The rules extracted for the set of data provided to the WEKA® Explorer analysis suggested a positive correlation between the attendance in the first four lectures (L1, L2, L3, L4) and the expected mark in the final examination. It also suggested that the enrolled programme (degree or diploma) was significant in the prediction of the exam mark. For illustrative purposes, the Expression Tree (REP Tree) output obtained from WEKA® Explorer shown in Figure 1 illustrates the dependence of the exam mark on early attendance and enrolled programme. The early detection tool generated with this expression tree (shown in Figure 2) provides a useful instrument for the lecturer as well as the student.

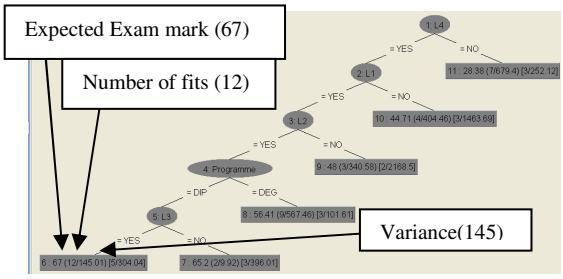

Figure 1: The REP Tree from WEKA®

INPUT PANEL	(Input data in blue cells)	
Your Programme =>	Type **DEG** or **DIP** =>	DIP
Attendance in Lecture 1 =>	Type **Y** or **N** =>	Y
Attendance in Lecture 2 =>	Type **Y** or **N** =>	Y
Attendance in Lecture 3 =>	Type **Y** or **N** =>	Y
Attendance in Lecture 4 =>	Type **Y** or **N** =>	Y

OUTPUT PANEL	EARLY DETECTION TOOL
Your expected exam mark M =>	67%
M + σ (Std. Dev.) =>	81%
M - σ (Std. Dev.) =>	53%

Figure 2: The "Early detection" tool

INPUT PANEL	(Input data in blue cells)	
Your Programme =>	Type **DEG** or **DIP** =>	DIP
The total number of lectures		10
Number of lectures you attend	Type a number=>	10
Your percentage attendance		100.0

OUTPUT PANEL	ATTENDANCE TOOL
Your expected exam mark M =>	72%
M + σ (Std. Dev.) =>	83%
M - σ (Std. Dev.) =>	61%

Figure 3a: The "Attendance" motivator tool

INPUT PANEL	(Input data in blue cells)	
Your Programme =>	Type **DEG** or **DIP** =>	DIP
The total number of lectures		10
Number of lectures you attend	Type a number=>	6
Your percentage attendance		60.0

OUTPUT PANEL	ATTENDANCE TOOL
Your expected exam mark M =>	61%
M + σ (Std. Dev.) =>	68%
M - σ (Std. Dev.) =>	27%

Figure 3b: The "Attendance" motivator tool

INPUT PANEL	(Input data in the blue cell)	
Assignment 1 mark out of 15	Type a value (no greater than 15)=>	4

OUTPUT PANEL	ASSIGNMENT TO EXAM TOOL
Your expected exam mark M =>	54%
M + σ (Std. Dev.) =>	74%
M - σ (Std. Dev.) =>	34%

Figure 4a: The "Assignment to Exam" tool (for assignment mark of 4)

INPUT PANEL	(Input data in the blue cell)	
Assignment 1 mark out of 15	Type a value (no greater than 15)=>	12

OUTPUT PANEL	ASSIGNMENT TO EXAM TOOL
Your expected exam mark M =>	54%
M + σ (Std. Dev.) =>	74%
M - σ (Std. Dev.) =>	34%

Figure 4b: The "Assignment to Exam" tool (for assignment mark of 12)

INPUT PANEL	(Input data in the blue cell)	
Assignment 1 mark out of 15	Type a value (no greater than 15)=>	12

OUTPUT PANEL	ASSIGNMENT TO EXAM TOOL
Your expected exam mark M =>	54%
M + σ (Std. Dev.) =>	74%
M - σ (Std. Dev.) =>	34%

Figure 5a: The "Assignment to Exam" tool (for assignment mark of 12)

INPUT PANEL	(Input data in the blue cell)	
Assignment 1 mark out of 15	Type a value (no greater than 15)=>	15

OUTPUT PANEL	ASSIGNMENT TO EXAM TOOL
Your expected exam mark M =>	90%
M + σ (Std. Dev.) =>	94%
M - σ (Std. Dev.) =>	86%

Figure 5b: The "Assignment to Exam" tool (for perfect assignment mark)

INPUT PANEL	(Input data in the blue cell)	
Test mark out of 20	Type a value (no greater than 20)=>	5.5

OUTPUT PANEL	TEST TO EXAM TOOL
Your expected exam mark M =>	17%
M + σ (Std. Dev.) =>	35%
M - σ (Std. Dev.) =>	0%

Figure 6a: The "Test to Exam" tool (Test 5.5)

INPUT PANEL	(Input data in the blue cell)	
Test mark out of 20	Type a value (no greater than 20)=>	11.9

OUTPUT PANEL	TEST TO EXAM TOOL
Your expected exam mark M =>	56%
M + σ (Std. Dev.) =>	71%
M - σ (Std. Dev.) =>	42%

Figure 6b: The "Test to Exam" tool (Test 11.9)

INPUT PANEL	(Input data in the blue cell)	
Test mark out of 20	Type a value (no greater than 20)=>	12

OUTPUT PANEL	TEST TO EXAM TOOL
Your expected exam mark M =>	76%
M + σ (Std. Dev.) =>	89%
M - σ (Std. Dev.) =>	62%

Figure 6c: The "Test to Exam" tool (Test 12)

INPUT PANEL	(Input data in the blue cells)	
The total number of lectures		10
Number of lectures you attend	Type a number=>	9
Your percentage attendance		90.0
Your Assignment mark (out of 15)	Type a value =>	13.0
Your Test mark (out of 20)	Type a value =>	17.0
Your Lab report mark (out of 15)	Type a value =>	11.0

OUTPUT PANEL	COURSEWORK TO EXAM TOOL
Your expected exam mark M =>	68%
M + σ (Std. Dev.) =>	79%
M - σ (Std. Dev.) =>	56%

Figure 7: The "Course work to Exam" tool

Overall attendance in lectures (Attendance worksheet)

It is reported that the most important factors in deciding whether to attend a lecture or not are the quality and clarity of the lectures, followed by conflicting deadlines for other classes, the lecturer's use of relevant examples, and the lecturer's ability to engage and entertain the students (Clay & Breslow, March/April 2006). Evidence illustrating a clear positive correlation between attendance in lectures and the final exam mark as shown in Figure 3a can be an effective motivator and an input into students' time-management. Moreover, the ability to "play" with the tool allows students to explore quantitatively the possible detrimental effects of absenteeism (Figure 3b).

Forecasting exam mark from uncontrolled assessment (Assignment to Exam tool)

The correlation between the assignment mark and the expected examination mark is positive but weak implying a low sensitivity at the low range and a high sensitivity towards near-perfect mark in this open book assignment. A change in the assignment mark from 4 to 12 makes no difference to the expected exam mark (Figure 4a &b) whereas a greater variation can be expected for high assignment mark (12-15) as seen in Figures 5a&b. It also implies that a mark as high as 12 in this assignment does not automatically forecast a high examination mark and that there is no room for complacency.

Forecasting exam mark from closed book assessment (Test to Exam tool)

The relationship between the test mark and the exam mark supports the view that the test conditions and student performance mirrors the exam reasonably well. In this case, these assessments are both closed book. The highest and average test marks are 92.5% and 45.8% respectively (18.5/20, and 9.16/20) while those for the exam are 93.3% and 53.1% respectively. As illustrated Figures 6a-c, there are three clusters of test marks that lead to three distinctive outcomes: <5.5 leading to failure (10 students in all, not shown in the figure), 5.5-11.9 an 'at risk' group who may barely achieve the required minimum of 40% in the exam (31 students), and 11.9-20 a comfortable pass (15 students).

Forecasting exam mark from coursework marks (Coursework to Exam tool)

Finally, the tool based on the investigation relating exam mark to coursework marks, enrolled programme, and overall attendance revealed that the exam mark is independent of the enrolled programme as shown in the tool (Figure 7).

Summary and future developments

This study was motivated by our intuitive expectation that students' success in a course depends on student attendance in lectures and marks achieved from assessments during the semester. It gave interesting insights into the predictability of individual students' final course outcome in a quantitative manner. To some extent, these indicators represent the degree of students' general level of engagement with their learning process. The main outcomes of this study are summarised below.

Usefulness of the Early Detection Tool:

For the lecturer: Early indicator to identify at-risk students, provides support for the drive to split the groups of diploma and degree programme students, and provides proof that the groups' differences in performance disappear towards the end suggesting equitable learning (perhaps though at a cost to one group). For students: Evidence supporting students' early engagement in the course. For management: Provides evidence supporting the need to enhance the learning experience of both groups by providing separate lecture streams in the early stages of the course.

Usefulness of the Attendance Tool:

For the lecturer: Justification for marking attendance as a sound data source for future use rather than a "trick" that can be perceived by some students to force them to attend. For students: A motivation to prioritise attendance and engagement, provides the encouragement based on proof to identify as being in a group with different prior learning experience requiring additional efforts at least at the onset of the course, and provides evidential proof that the group of students who have more advanced prior learning can not be complacent and ignore the importance of attendance; attendance is crucial irrespective of prior learning. For management: Provides evidence that students in different

programmes perform differently and further reflection is required before combining these two groups in the future. Steps must be taken to teach these two groups separately in smaller classes.

Usefulness of the Assignment to Exam Tool:

For the lecturer: Assignment mark only identifies those who are at the extreme upper end of performance and should not be used as an indicator of performance at the exam. For management: Provides proof that controlled assessments are a good mechanism to measure learning and must not be completely eliminated from the assessment regime. Attempts to assess learning only by open book assignments to increase course completion rates must be discouraged.

Usefulness of the Test to Exam Tool:

For the lecturer and management: Provides confirmation that the outcome of a closed book assignment early in the course is a good estimator of performance expected later from an examination. It is also a useful indicator when extrapolation of marks from coursework becomes the only option when a student makes a special assessment circumstances (SAC) when unable to sit the final examination.

Usefulness of the Coursework to Exam Tool:

For the lecturer: Provides confirmation of the need for at least one closed book event to be among the coursework to provide students with a 'reality check' of examination conditions. For students: Provides an opportunity to appreciate the need for proper preparation for an examination. Also provides an opportunity to redress the issue of low coursework mark and focus more effort for the remaining assessment (Lab Report).

The tools illustrated here can now be used by students and teachers in several ways. First, they must be tested for their ability to make accurate predictions using the data for a future student cohort. Second, the tools can be used in subsequent cohorts as a predictive and management tool, using the insights summarised above. However, it should be emphasised to the students that these predictive tools are based on data that reflect past students' efforts commensurate with the recorded outcomes. The tools cannot magically replace the hard work required to produce the desired outcome. It is also important to note that the tools' predictions are not irrevocable predestinations. Rather, they are 'reference projections'. In other words, if a student seeks a final grade better than the tool predicts, then that goal is possible with appropriate effort. Usefully, the tool gives indications to the student about what kinds of efforts may contribute to their desired goal.

From the experience of introducing a similar tool in Business school, some expected reactions to this tool are:

- Student reactions ranging from " You can see if you need to improve your efforts to get the grade you want" and "This would be great to have available for ALL courses. You could see in which courses you needed to put extra effort, compared to those in which you are 'on track' to achieve the grade you want." to "I don't really care about what my final grade might be. I just work on the next assignment to the best of my ability."
- Late adopters needing 'hand-holding' through the use of the tool, some seeking guidance too late in the semester with little time to make major changes to the outcome of their course grade.
- The students most at risk of low grades being the ones least likely to use the tools that would help them manage their learning process to gain superior grades.

As argued by Culver (2011), early intervention is the key. He says that "Traditionally, 'early-alert-and-intervention' programs have relied upon mid-term grades and/or referrals made by faculty and staff. At that point in the semester it may be too late to intervene appropriately. More effective early-alert plans can be developed using data known about the student at the time of admission, historical persistence patterns, first-semester and mid-year assessments, and course completion and success rates." (Culver, 2011b).

Conclusions

Two courses, one for engineering students and another for business students at the same tertiary education institute have been studied to find that final course grades could be predicted from students' behaviour (class attendance) and performance (assessments) during the first three to four weeks of the study semester. Our results corroborate the findings of other recent studies that identified the importance of active and early (e.g. by week three) intervention by teachers and managers in improving the engagement of weaker students in their studies. The early interventions indicated for the engineering students in this study include encouraging 100% attendance in all lectures and committing to perform well in the in-term tests as practice for end of semester examination. It appears that diagnostics tests for numeracy at the outset would give additional information to prepare for specific guidance to take remedial measures.

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