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Effectiveness of an evidence-based predictive model for motivating success in freshmen engineering students

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BACKGROUND

Although several testing mechanisms are available to lecturers to identify students not meeting entry level skills to engage them in bridging courses prior to enrolment in the intended course, implementing these tests is often not an option. Typically, lecturers are obliged to accept all students and subsequently find innovative ways to increase retention/success. We believe that engineering students will be more inclined to improve their behaviour if they are provided with quantitative evidence that their behavioural change can lead to success and improved course grades. Consequently, a year ago an evidence-based tool (MECS: Motivation, Encouragement, Completion, Success) to predict course outcome was developed based on its quantified relationships with student attendance, early engagement, performance in interim assessments using a data mining technique applied to information on a cohort of first year students enrolled in Fluid Mechanics in 2010. The results showed that good attendance in lectures and higher performance in interim summative assessments led to higher final examination results (Fernando & Mellalieu, 2011). The tool also helped lecturer detect at-risk students who need significant intervention by the lecturer, and/or change in behaviour by the student to succeed. The strength of these correlations between the final course outcome and other attributes was so strong that it signalled promising results from an extended study.

PURPOSE

The purpose of our on-going efforts was to find how best to use the MECS- tool to motivate and engage engineering students to achieve better course outcomes. The analysis sought answers to the question of what intervention mechanisms most effectively improved the course completion rates.

DESIGN/METHOD

The validity of the MECS-tool developed for the 2010 cohort of students was tested with data for the 2011 batch. Both groups did not use the tool and therefore did not benefit from its predictive capabilities enabling change of behaviour; as such the validation results help confirm if the tool is applicable in general. In 2012, the tool was given to the students enabling them to be in control of the desired outcomes. Intervention measures were also implemented. Comparison was then made between 2010 & 2011 performances with those in 2012. Feedback was gathered from the 2012 students on the usefulness of the tool.

RESULTS

Success in 2012 was superior to those in 2010 & 2011 implying the effectiveness of the MECS-tool in initiating behavioural changes and intervention techniques. Adoption of the tool for students was not widespread but an overwhelming majority recommended it be made available to future cohorts.

CONCLUSIONS

The tool is very effective in identifying at-risk students. It helps students adapt to achieve desired course outcomes. A combination of methods varying from encouragement to use the tool, intervention mechanisms such as persistent follow ups, catch-up lessons, and extra tutorials offered to the detected at-risk students were the effective ways that enhanced success and retention in 2012.

KEYWORDS
Data-driven modelling techniques, Tools for student motivation, Student success and retention.

Introduction

The most common way of achieving high retention and success in engineering courses is to have effective entry standards and pre-requisite requirements in place. To ensure that freshman students seeking to enrol in a course are able to follow through without extensive intervention it is common now for institutions to hold pre-entry diagnostic tests to identify those students who require gaps in knowledge be bridged before enrolment (e.g.(UofA, 2012). The screened students are then offered bridging courses. However, in many tertiary technical institutes in New Zealand difficulties in gauging if the freshmen satisfy the institutes' entry requirements are exacerbated by the plethora of quasi-scientific subjects available to high-school students and somewhat vague non-grade-based achievement outcomes. Furthermore, with time and resource constraints pre-diagnostic tests are unrealistic and the institutes are forced to take in any student who appears to meet the entry level requirements. Following admission, the institutes' teachers seek every possible approach to achieve high success and retention levels without sacrificing standards. In New Zealand, as in many other countries, the government subsidies offered to tertiary institutes are becoming increasingly based on course completions rather than enrolments. Consequently, these institutes are actively seeking ways to improve course completion rates.

The Department of Civil Engineering at Unitec Institute of Technology, offers a 3-year undergraduate degree and a 2-year diploma. First year courses, such as Mathematics and Fluid Mechanics, which rely on proficient numeracy skills experienced relatively high failure and dropout rates as high as 40-50% of enrolments. Among the several factors contributing to these low success rates are (Fernando & Mellalieu, 2011):

• 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" (Coolbear and Schöllmann in(Whatman, Potter, & Boyd, 2011)).

Students' under-estimation of the level of engagement required to successfully complete a course is a major barrier to their achievements. Grade forecasting tools have reportedly helped overcome the problem of complacency of engineering students by indicating the real amount of study time necessary to be successful (Wells, 2001) and a successful application of such a tool has been reported in another school in this institute (Mellalieu, 2011). Although anecdotal evidence of correlations between student behaviour prior to the final examinations and the final outcomes is found, quantifying these correlations is difficult. A quantifiable relationship between TOEFL scores and academic success of international engineering students has been reported (Wait & Gressel, 2009). A correlation noted by academics between an assignment and success during a freshman year has been successfully used to predict academic success of freshman Engineering students (Lackey, Lackey, Grady, & Davies, 2003).

We presumed that engineering students will be more inclined to adopt success-oriented behaviour if they are provided with quantitative evidence that appropriate behavioural change can lead to success and improved course grades. Consequently we undertook to develop a five-component decision support tool for use by students and the lecturer. As a preliminary step towards achieving this goal, explicit, quantitative patterns between student behaviour and the outcomes achieved were identified using the data modelling workbench, WEKA®. These patterns were derived from the data collected for the cohort of students enrolled in Fluid Mechanics in 2010. The data used, the method of eliciting correlation functions, and utility and function of each component of the tool was detailed previously (Fernando & Mellalieu, 2011). The initial investigation was motivated by our intuitive expectation that students' success in a course would depend on student attendance in lectures and marks achieved from summative assessments prior to the final examination. Our subsequent analysis identified interesting insights into the predictability of an individual's final course outcome in a quantitative manner. The patterns thus identified showed weak as well as strong correlations between student success and the suspected contributing factors. Some of the strongest associations with successful completion of this course were early engagement (measured by attendance) and performance in a closed book assessment. The parameters estimated for the tool were validated using data for the cohort of students in 2011.

This provided us with confidence to utilise our data-driven insights to enhance student success through specific behavioural changes on the part of the students through establishing early intervention and support mechanisms. Finally, the tool was deployed with the 2012 cohort of students and its effectiveness gauged.

Aim

The aim of our efforts over several years was to find how best to motivate and engage engineering students to achieve better course outcomes. There is ample research reporting the study habits of engineering students, what motivates them to achieve success, and their perception of influencing factors (Baillie & Fitzgerald, 2000; Blumner & Richanrds, 1997; Hutchison, Follman, & Sumpter, 2006). A few numerical models that help determine or predict the success and/or attrition have been developed (Besterfield-Sacre, Atman, & Shuman, 1997; Mendez, Buskirk, Lohr, & Haag, 2008; Moller-Wong & Eide, 1997; Wells, 2001). However there is little evidence of studies where a predictive tool has been given to students (and staff) to make decisions and apply intervention mechanisms (Mellalieu, 2011). Specifically, we sought to gauge the effectiveness of intervention mechanisms in improving the course completion rate. The traditional methods we deployed to encourage their students had limited success; they included suggestions that students should engage early with their learning during their course of study, 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 proposed that a tool based on a data-derived model that produces quantitative, predicted outcomes would be more acceptable to engineering students as providing a student with the means to predict quantitatively their personal academic success and final grade as they progress through their course. In response to the prediction, students may choose to make behavioural changes to optimise the outcome they seek. However, it pays to remember that when trying to influence students' learning behaviours that students' goals for themselves may differ from their teachers' goals for them (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010))!. For instance, there is a risk of our tool being used to optimise efforts to achieve a minimal pass rather than maximise efforts for a maximum pass grade. However, we argue that that is a choice for students to make in an informed manner.

Method and data

The following sub-sections outline the method and data used in the development of the tool, its validation, and its eventual deployment in 2012.

Development of the tool

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). Readers are referred to the process of developing MECS-tool which is explained in detail in a previous publication (Fernando & Mellalieu, 2011). In this study, MECS- tool developed using the data for 2010 was validated against the 2011 data. Finally, the tool was given to the 2012 students at the start of the semester. The MECS-Tool (Motivation, Engagement, Completion and Success) is an Excel spread-sheet comprising five sheets representing five component tools.

Table 1 shows the number of students enrolled in the Fluid Mechanics in each programme, the class size, and lecture configurations in each of these years. There are some differences in the size of the cohorts. The larger number encountered in 2011 led to the class to be divided into two groups to ensure a better learning experience and cope with limited lab facilities. In 2012, however, due to time and other resource constraints the class was not divided despite the higher number than 2010.

Table 1: Summary of data on student cohorts used in the study

Year	2010	2011	2012
Diploma Students (DIP)	30	44	13
BEngTech Degree students (DEG)	26	35	55
Total students	56	79	68
Students in a lecture	All	35 or 45 at a time	All
Lectures and Tutorials	10 x 4hr	2hr x 18 + 4 hr x 1	2hr x 20

Table 2 summarises the input variables in the MECS-tool, the types of assessment, and their course weight. The predicted outcome of all the tools is the expected final examination mark (Mean) and its statistical bounds (± std.dev).

Table 2: Contributing factors affecting the course outcome

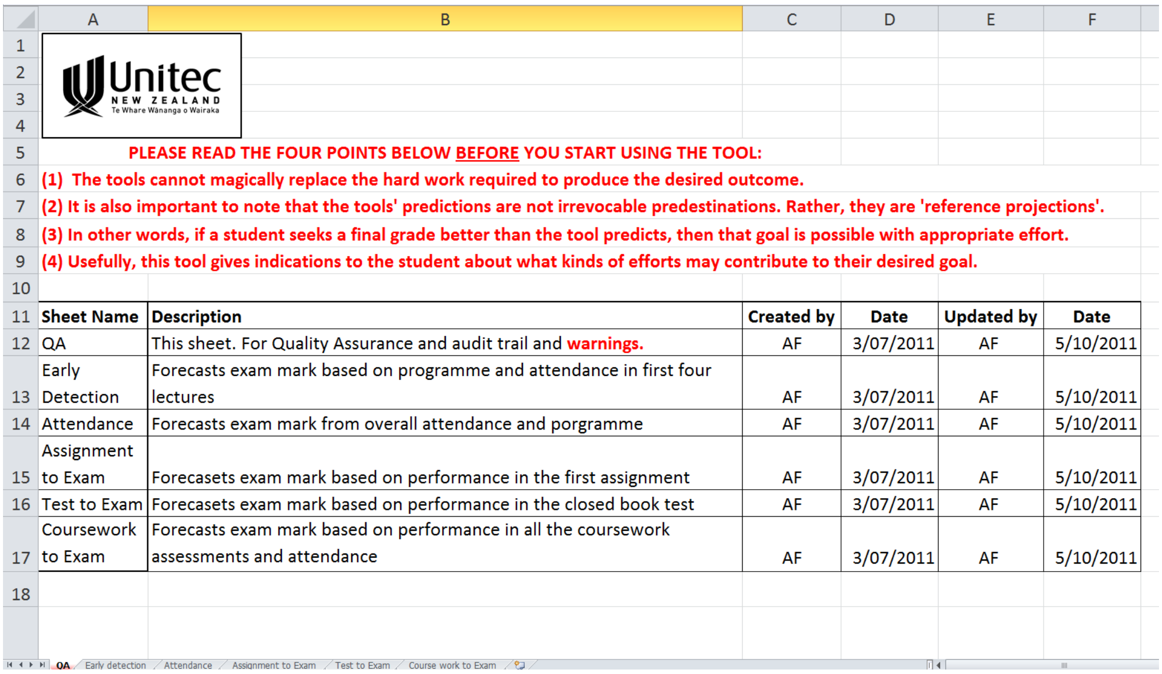
	Factor	Description	Course Weight(%)
Input	Enrolled Programme	Degree (DEG) or Diploma (DIP)	-
Input	Assignment	Open book assessment	15
Input	Test	2 hour closed book assessment	20
Input	Lab Report	Open book assessment	15
Input	L1	Attendance in Lecture 1	-
Input	L2	Attendance in Lecture 2	-
Input	L3	Attendance in Lecture 3	-
Input	L4	Attendance in Lecture 4	-
Input	Overall attendance	A number out of 10	-
Output	Examination	3 hour closed book exam	50

The five component tools incorporate several factors that affect (significantly) the final course outcome as input parameters. Table 3 summarises these input parameters used for each component tool and their possible range of input values.

Table 3: Components in MECS Tool and input factors affecting the course outcome

Component tool	Input parameter in the component tool	Input value
Early detection	Programme	DIP / DEG
	L1, L2, L3, L4	Y / N for each
Attendance motivator	Programme	DIP / DEG
	Number of lectures attended	A number: 1-10
Assignment to Exam	Mark obtained for the Assignment	A value: 1- 15
Test to Exam	Mark obtained for the Test	A value: 1-20
Coursework to Exam	Number of lectures attended	A number: 1-10
	Mark obtained for the Assignment	A value: 1-15
	Mark obtained for the Test	A value: 1-20
	Mark obtained for the Lab Report	A value: 1-15
Component tool name	Input parameter in the component tool	Input value

The MECS-Tool spread-sheet was placed on the front page of the students' learning management system (Moodle). Students were encouraged to use the tool as they progressed through the semester. Figure 1 shows a screen shot of the front page of the MECS-Tool with the names of the component tools on the subsequent sheets visible on the bottom tabs (Early Detection; Attendance, etc.).



PLEASE READ THE FOUR POINTS BELOW BEFORE YOU START USING THE TOOL:
(1) The tools cannot magically replace the hard work required to produce the desired outcome.
(2) It is also important to note that the tools' predictions are not irrevocable predestinations. Rather, they are 'reference projections'.
(3) In other words, if a student seeks a final grade better than the tool predicts, then that goal is possible with appropriate effort.
(4) Usefully, this tool gives indications to the student about what kinds of efforts may contribute to their desired goal.

Sheet Name	Description	Created by	Date	Updated by	Date
QA	This sheet. For Quality Assurance and audit trail and warnings.	AF	3/07/2011	AF	5/10/2011
Early Detection	Forecasts exam mark based on programme and attendance in first four lectures	AF	3/07/2011	AF	5/10/2011
Attendance	Forecasts exam mark from overall attendance and porgramme	AF	3/07/2011	AF	5/10/2011
Assignment to Exam	Forecasets exam mark based on performance in the first assignment	AF	3/07/2011	AF	5/10/2011
Test to Exam	Forecasets exam mark based on performance in the closed book test	AF	3/07/2011	AF	5/10/2011
Coursework to Exam	Forecasts exam mark based on performance in all the coursework assessments and attendance	AF	3/07/2011	AF	5/10/2011

QA / Early detection / Attendance / Assignment to Exam / Test to Exam / Course work to Exam

Figure 1: The front sheet of the MECS Tool

Validation of the tool

In this context validation implies testing the applicability of the model on a similar cohort of students operating under similar conditions. There were a few differences (noted in Table 1) in terms of class size, the duration and frequency of lectures which could have influenced student performance. Consequently, the assignment marks were compared to see if there were major differences between those in 2010 and 2011. Table 4 summarises the relevant statistics that supports the view that the statistics of the marks obtained by the students are not significantly different between 2010 and 2011 assuring that the distribution of marks across the cohort are similar in these two years. Consequently, no adjustments were made to the ranges of marks within the tool.

Table 4: Comparison of assignment marks between years

Year	Statistic	Assignment (15%)	Test (20%)	Lab Report (15%)
2010	Mean	9.8	9.2	10.8
	Median	11.0	9.1	11.7
	Standard deviation	3.8	4.2	3.5
2011	Mean	10.3	7.0	10.6
	Median	11.2	6.4	10.6
	Standard deviation	3.5	4.8	3.4
2012	Mean	11.2	11.7	10.6
	Median	12.0	12.6	10.6
	Standard deviation	3.8	4.8	2.5

Deployment of MECS-tool

The 2012 students used the MECS-Tool to predict the final examination outcome at various stages. The lecturer too used it at the end of the first four lectures to identify the at-risk students. Following up on the absentees to find out the reasons for absenteeism, providing suggestions to overcome these barriers, offer of support and suggestions to catch up on missed lesson(s), and verbal encouragements were some of the remedial actions taken. After the outcome of the closed book assessment was available, further remedial action were deployed to offer help to the at-risk students.

At the end of the semester a questionnaire was distributed to all the students where they responded voluntarily to a few questions regarding the use of the MECS-tool, its impact, and behavioural changes, if any, they adopted after using the tool. Of the 38 that returned the completed survey, 16 had used the tool.

Results

As shown in Table 5, the course completion rates for 2010 (71%) and, in particular, 2011 (61%) were poorer than for 2012 (76%).

Table 5: Comparison of completion rates

	2010		2011		2012	
	Number	%	Number	%	Number	%
Total	56	100%	79	100%	68	100%
Pass	40	71%	48	61%	52	76%
Fail	16	29%	31	39%	16	24%

The year 2011 was an unusual episode when an unexpected number of Diploma students were admitted to Unitec who had completed the pre-requisites outside the institute. Their prior learning, analytical skills, punctuality, and attendance patterns were observed to be substantially inferior to those admitted under Unitec's 'normal' policies. In contrast, the completion rate of the 2012 cohort is the highest suggesting that perhaps students' ability to adopt corrective measures to achieve has contributed positively. In fact, more than half of the 16 students who stated that they used the MECS-tool to change their behaviour stated that as a result of using the tool they (1) worked harder on remaining assignments (2) allocated more time for revision and tutorials, and (3) determined not to miss lectures. Furthermore, seven students stated they (1) chose to attend additional catch-up tutorials offered by the lecturer (2) decided to undertake assignments to a higher standard, and (3) started work on previous years' exam questions early. All these behavioural changes we suspect have contributed to these students' higher success rate. All the 16 users thought the tool was interesting, 15 found it useful, 13 used it to predict the likely outcome for the course, 10 played with it to check out different scenarios. The only respondent to the question "what did you NOT like about the tool?" said "It told me that I could 'fail' and it's not nice to know that".

Of the specific students who eventually failed the paper, the numbers that were identified prior to the final examination by each component tool of MECS-Tool are shown in Table 6.

Table 6: Ability of the components in MECS Tool to detect students who eventually fail

	2010		**2011**		**2012**	
	Number	%	Number	%	Number	%
Detected - Early attendance	8	50%	17	55%	8	50%
Detected - by 1st Assignment tool	5	31%	4	13%	3	19%
Detected - by Test tool	9	56%	23	74%	9	56%
Detected - by overall attendance tool	12	75%	4	13%	7	44%
Detected - before exam	10	63%	26	84%	10	63%
Failed but undetected	0	0%	0	0%	4	25%

Apart from the component tool "Assignment to Exam" all the other sub-tools are effective in that they predict around one-half of the students who will eventually fail. The Assignment, being an uncontrolled open-book assessment, does not gauge accurately the knowledge and skills of an individual who may rely on others to complete the assignment. The two most useful component tools to detect at-risk students in time to take remedial action are "Early detection" and "Test to Exam". Accordingly, in 2012 a total of 25 students detected by these two component tools were notified and encouraged to participate in five catch-up tutorials organised and conducted in the lecturer's own time but at a time convenient to all parties after consultation. An average of 16 students attended the first four sessions; the fifth session, closest to the examination, was attended by 26 including those not necessarily at-risk. Seven of the (notified) students who eventually failed did not attend any of these five catch-up tutorials. Among those who attended were five who benefitted greatly and, in the lecturer's opinion, may not have been successful without this additional help. However, two students who attended these catch-up lessons and made good progress still failed to achieve the minimum marks albeit marginally.

It is very encouraging that more than half the at-risk students can be identified quite early on in the course's progress. With all the possible remedial action in place, it could be seen that the 2012 cohort reached its potential commensurate with their skills, ability and willingness to commit time to remedial action.

Another interesting outcome is that unlike in the previous two years, four students who failed were undetected by the tool. A feature common to two of these four students is that this is not their first attempt at the course. Both students, having completed coursework and attended lectures/tutorials, then attempted to 'game' the assessment regime. They focussed on studying specific areas of the syllabus and answered a select few questions in the examination seeking to achieve sufficient marks to pass the course. Upon close inspection, these two students' coursework marks were just high enough not to be detected as 'at-risk' by the MECS-tool.

The students' feedback on their use of the MACS-Tool also ranked the following factors as the most significant barriers to achieving their goals for this course (1) Lack of time to revise between lectures (2) Vast amount of new theory to learn in a semester (3) Insufficient prior learning (4) Class size (72 students) too large.

Conclusions

The main conclusions of this study are :

(i) Data mining is effective in extracting associations between in-course performance, attendance and final course outcomes;

(ii) The associations derived by data mining enabled the deployment of a quantitative tool attractive for use by engineering students to guide their study behaviour;

(iii) The tool developed from the 2010 student cohort was found valid in predicting course outcomes for the 2011 group. In the 2011 'validation' cohort, students were not provided access to the tool, and the lecturer offered no additional classes informed by the tool. Observed variations between 2010 and 2011 were mainly due to the increased size of the class and the lecturer's other strategic changes made to course delivery;

(iv) Use of the MECS-tool by the lecturer and the students in 2012 has positively influenced retention and course completion;

(v) For teachers with engineering courses that are challenged by maintaining high success and retention we advocate the use of (a) data mining analysis of students' attendance and in-course performance (b) decision support tools, like MACS-Tool deployed for guiding both student and lecturer intervention.

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