Dealing with the Tail: Remedial Tutorials for Second-year Electrical-engineering Students

Gerard Rowe[1], Chris Smaill[1], Elizabeth Godfrey[2], Lawrence Carter[1], Bernard Guillemin[1], Mark Andrews[1] and Waleed Abdulla[1]

[1] The University of Auckland, Auckland, New Zealand
{gb.rowe, c.smaill, lj.carter, bj.guillemin, m.andrews, w.abdulla}@auckland.ac.nz

[2] The University of Technology, Sydney, Australia
egodfrey@eng.uts.edu.au

Abstract: *An intervention aimed at improving the success rate of at-risk students in three key second-year electrical-engineering courses covering, respectively, the topics of circuit theory, electronics and electromagnetics is reported. At-risk students are identified by a combination of diagnostic testing and early coursework results. These students are then invited to join a special, weekly, "Foundation Tutorial" in which both technical and learning obstacles are addressed. Two years of data are presented which suggest that such an intervention does produce a significant improvement in the success rate of participating students.*

Introduction

For some years, considerable engineering-education research effort has been directed internationally toward improving student success in first-year programmes by evaluating strategies which have ranged from curriculum redesign to interventions aimed at increasing academic and social integration (Baillie, 1998; Bernhold, Spurlin & Anson, 2007; French, Immekus & Oates, 2005). Investigations of students' academic preparedness (Lee, Harrison, Pell & Robinson, 2008; Robinson & Croft, 2003; Smaill, Godfrey & Rowe, 2008, 2009), student study practices (Tait & Entwistle, 1996) and engagement with their own learning have been useful in identifying students at risk of failure. The provision of supplemental instruction for at-risk students (Webster & Dee, 1998) has been found to be effective in improving the grades of such students. While this remains a very active research area, similar attention is now starting to be focussed on the second and subsequent years when students encounter core discipline-specific courses. As developers of course-concept inventories and researchers of threshold concepts will attest, a pass in a particular first-year course, or indeed the entire first year of study, is no guarantee that the student has mastered all of the relevant technical material or achieved a sufficient level of academic independence. On the contrary, the student may still have significant conceptual misunderstandings or learning difficulties. If these remain undetected and uncorrected, the future academic success of that student is threatened.

This paper reports an intervention aimed at improving student success in three key second-year electrical-engineering courses covering, respectively, the topics of circuit theory, electronics and electromagnetics. These papers can be considered to contain the theoretical underpinnings for a degree program in Electrical Engineering, and at this institution they have proved for many years to be "gate-keeper" courses in terms of progression through the degree. For the last two years, at-risk students have been identified by a combination of diagnostic testing and early coursework results. These students have then been invited to join a special, weekly, "Foundation Tutorial" in which both technical and learning obstacles are addressed. Two years of data are presented which suggest that such an intervention does produce a significant improvement in the success of participating students.

Methodology

In each core second-year course, at-risk students were identified by a combination of diagnostic testing and analysis of early course-work results. Typically a (not-for-credit) diagnostic test would be administered without warning in the second lecture of the course. Such a test would usually be based on key concepts, and use the same principles as underpin most concept inventories (Steif & Hansen, 2007). Students with very low marks (thus identified as being at-risk of failure) were then contacted by email, advised of their “at-risk” status and invited to attend an extra weekly tutorial to help improve their chances of successful course completion. For two of the courses, additional evidence available from analysis of early course-work results was used to instigate a second round of invitations.

One possible explanation of student “at-risk” status is a mismatch between the student’s preferred learning style and the delivery style adopted in a particular course. For this reason, the first tutorial (run by a lecturer) provided an introduction to learning styles (Felder and Brent, 2005), and the attendees were given the opportunity to attempt the Felder-Soloman Index of Learning Styles (ILS) questionnaire (Felder & Soloman, 1998). Assistance with the interpretation of individual ILS results was provided. Subsequent tutorials (run by senior PhD students who aspire to academic careers) dealt with relatively low-level technical issues on circuit theory, electronics and electromagnetics. Postgraduate students were chosen as tutors because it was felt that the at-risk students would relate better to younger student tutors than to predominately older academic staff. Initially the tutorial sessions involved the tutors working slowly through a small number of carefully chosen problems. Realising that this style might not have engaged the students, and indeed might have simply replicated the traditional lecture style, in the latter tutorials the tutors incorporated a more interactive style to encourage active learning on the part of the attendees. In this way an attempt was made to address perceived inadequacies in student-learning strategies. As noted later in student-interview comments, these latter sessions were acknowledged by the at-risk students as being particularly effective.

While such tutorials address cognitive barriers to learning, other issues may also be responsible for at-risk behaviour. For this reason the tutors (and the course lecturers) also looked for non-cognitive problems with the intention of referring such students to a separate Pastoral Care network.

The effectiveness of the intervention was investigated via analysis of examination results (for attendees and non-attendees) and by interviews (conducted by an academic staff member experienced in qualitative research), with both the students and the tutors. Results of this analysis and interpretation of the (anonymised) interview transcripts are provided in the next section.

Evidence of Success

Examinations

Foundation tutorials have been run in three courses across three semesters. The courses involved are *Circuits & Systems* (for which two year’s data is available), *Electronics* and *Electromagnetics*. In the case of *Circuits & Systems*, in 2008 for a class of 149 students, 42 were identified as being at-risk. Of these, 10 attended 50% or more of the six foundation tutorials offered. Nine of these 10 students subsequently passed the course. Of the other 32 students identified as being at-risk who did not avail themselves of these tutorials, 12 subsequently failed the course. Overall a total of 17 students failed the course, of whom 13 had earlier been identified as being at-risk, with only one attending the foundation tutorials regularly.

In 2009 133 students enrolled in *Circuits & Systems*, and 63 were identified as at-risk. Of these, 20 attended six or more of the 13 foundation tutorials offered. Of these 20 students, 17 subsequently passed the course. Of the other 43 students identified as being at-risk who did not regularly avail themselves of these tutorials, 20 subsequently failed and one withdrew before the final exam. Overall a total of 22 students failed the course, including 20 who had earlier been identified as being at-risk, of whom only five attended six or more of the foundation tutorials.

Electromagnetics, for which only 2008 data is currently available, had 35 students identified as being at risk. A total of five foundation tutorials were run with only nine students attending one or more of these tutorials. Of these nine students, five subsequently passed the course. In the case of the other 26 students who attended no tutorials, 11 subsequently failed the course, while two students withdrew before the final exam.

In *Electronics,* for which only 2009 data is available, 38 students were identified as being at-risk from a total class size of 131. A total of five foundation tutorials were run in the latter half of the semester. Of the 16 students who attended one or more of these tutorials, 13 subsequently passed the course. By contrast, for the 22 students who attended no tutorials, 16 subsequently passed. However, we were less successful at identifying at-risk students in this course than we were for *Circuits & Systems*. In particular, of those students who failed this course, only 50% had been identified as being at-risk.

To quantify the effect of foundation tutorials on student performance we analysed performance in *Circuits & Systems* and *Electronics* in 2009. We began our analysis by partitioning the at-risk students into two categories: those who attended one or more foundation tutorials and those who did not. Histograms of the final marks achieved by students in each category describe the general performance of the separate cohorts and we assume that each category can be adequately summarised by its mean and standard deviation. A natural measure of inter-category distance is therefore the difference in category means, moderated by the uncertainty in distance expressed by the category standard deviations. Cohen introduced the normalised difference between means (called *effect size*) as a way to quantify the effect of a procedure or treatment (Cohen, 1988) and we have adopted the Cohen effect size to examine the efficacy of foundation tutorials.

Given two categories with sample sizes N_1 and N_2 we compute the category means μ_1 and μ_2 and corresponding sample standard deviations σ_1 and σ_2. The normalised distance d between the categories is then given by $d = \frac{\mu_1 - \mu_2}{s}$ where $s = \sqrt{\frac{(N_1 - 1)\sigma_1^2 + (N_2 - 1)\sigma_2^2}{N_1 + N_2}}$

Note that the parameter s^2 is a weighted combination of the category sample variances, with relatively more emphasis given to the category with more samples. For an effect well-separated from the control category, s will be small for a given $\mu_1 - \mu_2$ (since the category variances σ_1^2 and σ_2^2 will be small), thus d will be "large." For cases where either category is dispersed (and therefore has a larger category variance) the increased value of s serves to reduce the distance between categories and d will be "small."

For the at-risk students in *Circuits & Systems*, Cohen's effect size was 0.720. This is considered a large effect and indicates that the students who attended the foundation tutorials positively benefitted from the additional instruction and activities. The corresponding analysis in *Electronics* produced an effect size of just 0.014. This is considered a very small effect and implies that the foundation tutorials provided no benefit to participating students. However, a closer examination of the methodology used reveals some complicating factors. The diagnostic tests are not precision instruments and when administered very early in the semester can inadvertently identify highly-capable students as being at risk. These students may correctly decide that they do not need the services of the foundation tutorial programme, but they are still recorded in the sub-category of having not attended the tutorials but passed the examination. Such students have the effect of reducing the normalised inter-category distance because they erroneously raise the average performance of the non-attending group. This effect was much stronger for the *Electronics* course (46% of nominally at-risk students) than for the *Circuits & Systems* group (11% of nominally at-risk students).

If we exclude from the non-attendance category those students who passed the examination (on the basis that they were incorrectly identified as being at risk) then Cohen's effect size increases to 1.891 for *Circuits & Systems* and 1.443 for *Electronics*. These effect sizes are considered very large and indicate a strong positive benefit for those attending the foundation tutorials. It should be clear that these quantitative measurements are sensitive to the methods and tools used to initially identify at-risk students and the criteria used to partition those students for analysis. More work needs to be done to improve the selectivity of the diagnostic tests and this is the subject of on-going research.

Student Interviews

The student interviews probed three issues, namely: why students initially seen by the university as academically able were being identified as at-risk just one year later, whether the foundation tutorials enhanced learning, and what recommendations the students had for improving their learning.

All but one of the interviewees confirmed that Electrical and Computer Engineering was their chosen specialty i.e. they hadn't been forced into this discipline because their chosen discipline was over-quota. Not surprisingly, a wide range of issues were identified as contributing to their at-risk status. Some of these could be considered related to their ability to take responsibility for their own learning such as time management, not doing enough practice, poor maths and physics background, motivation, shallow learning, and needing to adapt their learning style to the predominant style of course delivery. The following quotes (in the students' own words) summarise these reasons.

"I just kept delaying saying I'll get to it, I'll get to it…but too little too late is what I'm thinking."

"The only reason I fail those papers last year was because I just didn't have enough practice on it……So in a way it's a good thing to fail you realise you have to take care of more practice and you should be fine."

"Well basically two main reasons. One is probably my maths and physics not strong enough and second my problem solving skills that is I think, I believe mainly due to the lack of practice..."

"I was not fully motivated to give it my 100% so to speak."

"..not a lot of the info we learnt remained in my head… you learn and do the best for the exams and then you choose to forget and you don't keep."

"Well now I realise that knowledge I get from second year I don't throw it away, I have to use it on third and fourth and for the rest of my life."

"I am learning to study in a different way."

Other issues demonstrated that personal or non-cognitive issues have a significant impact on the students' ability to learn and retain knowledge.

"Hm..when I started this study last year I had broken relationship, financial problems, no job and probably changed my evaluation of the people... It took me quite a bit of effort...got over that, but now I'm all right."

"...I think relationships do make studies difficult. Had rough times with my girlfriend and in those time didn't want to study at all and fell behind like two to three weeks of material and then just lost interest in studying..."

"Well actually I am quite busy, like I'm in the Army Reserves and that takes a weekend and Saturday and Tuesday night a month and sometimes even more and I also do a bit of volunteering work with refugees. I've got a refugee family so it takes a fair chunk of my weekends away. Otherwise I could actually be doing study so yeah I've had to practice time management quite a bit."

"As a mature student, family difficulties is the main issue. Because you have to make sure you have spare time with your children, your wife and then your studies."

Of most concern was the student who acknowledged not attending lectures, raising the question – to what extent is it the responsibility of the institution to follow up absenteeism by way of pastoral care?

"First off, this semester I was definitely not motivated to attend lectures and so on, as I was the only one of my friends that chose Electrical and found that slightly, I guess, de-motivating in itself, so it seemed very daunting to go into the lecture theatre and sit by myself, and the fact that I'm quite shy and can't introduce myself to others easily did not help."

The interviewees seemed to be appreciative of the effort involved in setting up the foundation tutorials and generally felt attendance had been beneficial for their learning.

"…it's much easier interacting with student teachers, mentors than lecturers."

"It [the Felder ILS Questionnaire] *was insightful."*

"The ELECTENG 202 tutors were great."

"The tutors were really good. Their approach is different from that given during the lectures. They are more focussed on method of solving the problems, like question you should be asking yourself before attempting any problem."

"This is a good way of isolating the average student from the bright ones. Like in most cases discussion and question during normal tutorials are dominated by these bright students. So these special tutorials will give them more like a one-to-one peer tutorial."

Tutor Interviews

The items of interest that arose from review of the transcripts of the interviews conducted with the tutors were their perception of the students' ability, the appropriateness of the classroom activities and learning spaces, their perception of the degree of success of this intervention, and their opinions of the usefulness of the tutor training and course-coordinator briefings they had received. The tutors, all academic high-achievers, were surprised at the low technical level of the misunderstandings hindering the students and at the extremely passive approach adopted by many of the students.

The tutors had only attended conventional tutorials themselves as undergraduates. Subsequently, they had been trained for tutoring in such tutorials, and so they began their foundation tutorials by using conventional tutoring approaches. To varying degrees, and in somewhat different words, all the tutors expressed the opinion that using traditional tutorial teaching methods wasn't particularly effective for this cohort of at-risk students. All of the tutors experimented to some extent with other approaches designed to get more student engagement. Their comments reflected a desire for better training in techniques appropriate for such an at-risk cohort, and for better briefings from course coordinators.

Several of the tutors expressed concern about the appropriateness of the allocated learning space which was a lecture theatre with fixed seating, making interaction and working with small groups quite difficult. Another tutor felt a longer tutorial (three hours instead of the one hour scheduled) would have been better (although no student feedback on this suggestion has yet been tested!)

Evaluation and Suggested Improvements

Quantitative analysis of exam results, as well as evidence from interview transcripts, clearly shows that, despite seeing that some improvements could be made, the intervention was successful. For instance, for the 2009 *Circuits & Systems* course (which had the largest number of tutorials and attendance), comparison of exam results for those who attended more than one tutorial ($n=37$) with those who attended either none or only one ($n=27$) strongly reinforced the view that the effect of attending the tutorials was a significantly improved ($p=0.002$) exam mark. Our decision to use senior postgraduate students as tutors was the correct one and the process we used to select these tutors was effective. Our intention is to continue with the use of foundation tutorials, albeit with significant modification. Three areas in particular have been identified as needing improvement.

The first area concerns the at-risk cohort. We would like to improve the accuracy with which we identify at-risk students and will make more use, in future, of past academic record. Notably, a high proportion of the regular tutorial attendees had transferred into Electrical Engineering from non-traditional backgrounds and recognised that they had some catching-up to do. Their motivation was therefore high. Similarly we wish to increase the percentage of at-risk students who attend the tutorials, perhaps by including early social events to encourage relationship building and by more extensive individual follow-up. Finally, we have identified a need to separately identify those students needing pastoral care, in addition to assistance with conceptual misunderstandings.

The second area concerns the activities conducted during the tutorials. More attention needs to be paid to briefing at-risk students on strategies they could follow once they know the results of their Felder ILS questionnaire. This seems to be especially important for global learners. The use of a wider range of pedagogical styles in the tutorials is called for. To this end, the authors plan to involve specialists from our Student Learning Centre in the re-design of the tutorial activities, to better cater for the diversity of learning styles and conceptual misunderstandings identified by the tutors in the course of this pilot study and to encourage more active learning. A specialist training programme will be developed for the tutors involved in the foundation tutorials. The interviews with the tutors also highlighted a need for better coordination of the activities across all three courses, as many of the at-risk students were common to all three courses. Issues with the learning space clearly need addressing – because of space issues, the room allocated was a standard large lecture theatre and was not well-suited to small-group work. A more appropriate venue will be sought in future.

The final area concerns evaluation. A more formal evaluation of the effectiveness of the tutorials as perceived by the tutorial attendees needs to be conducted to supplement the evidence available from examination results and from student and tutor interviews.

Conclusions

Supplemental instruction (in the form of foundation tutorials) has been implemented for three courses in the second year of an Electrical and Computer Engineering programme with the aim of improving pass rates of students identified as being at-risk. Analysis of results from three semesters of this intervention shows that the intervention has been successful. Specifically, there is evidence that at-risk students who attend all (or most) of the foundation tutorials tend to pass the course. On the other hand, at-risk students who attend no foundation tutorials have a higher probability of failing the course. Interviews with student attendees have confirmed that they find these tutorials of benefit. For the next phase of this research project, the authors plan to involve specialists in student learning and in academic development to improve the design of the tutorial activities and to devise a training program for the tutors running these tutorials.

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