

Applying Experiential Learning with Success

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Abstract

The tertiary education sector faces increasing pressure to deliver more graduates with improved levels of skill whilst having fewer students fail subjects throughout their time of study. In engineering education the situation is even more complex with many universities having to accept students with lower ENTER scores to fill quotas. Historically, students with borderline ENTERs have shown great difficulty during their first year in the engineering degree program. Worse, the transition from first year to second year is often more difficult than from school to first year. The “smoothing-in” of school graduates into the first semester of first year is seen as a transition period, with second semester being the first “full-on” engineering semester of study. The challenge that now faces many universities is a balancing act of gradually introducing students into first year whilst minimising the shock that will await students when commencing second year. At Swinburne University of Technology, a system of experiential learning has been tried over the past year with great promises for success. The system comprises of a combination of projects, large assignments, and regular assessments. Students are guided to analyse, ponder and evaluate class problems in a more real-world manner, and regular assessments ensure that they stay up to date. Project work is employed to encapsulate as much of the disciplines that the student have been exposed to into a single meaningful real-world engineering task.

Introduction

Entrance into tertiary engineering study is achieved from a number of different routes, including end of high school exam scores, (ENTER (2005) which is a student rank order derived solely from Year 12 results), pathways from a TAFE institute (for those students holding a diploma or associate diploma), and mature age entry schemes for those students returning back to study without formal entrance requirements. Prediction of success by first year students has been shown to be highly dependent on scores achieved in high school exams at the end of year 12 studies (Taylor, 1983; James, 2001; Vialle, 1996; Everett, 1991; and Yorke, 2004). This prediction has also been successfully implemented in determining academic success by postgraduate students undertaking medicine studies (Blackman 2004). Over the past two years many Australian engineering faculties have seen a reduced number of entries into the first year of study. To overcome this problem several universities have resorted to a lower ENTER score requirement in order maintain student numbers. This strategy has brought its own problems, e.g. the students’ ability to progress through the course in the minimum amount of time (James, 2001; Vialle, 1996; Schonell, 1962). Universities may have maintained student numbers at first year level, however to be able to maintain student pass rates in subsequent years have proven to be extremely difficult.

At Swinburne University of Technology, the ENTER requirement has been reduced from 80 in 2004 and earlier, to 75 in 2005. The work reported in this study investigated the effect of lower ENTER scores on the success rate of passing three first year subjects, Mathematics 1, Physics 1 and Mechanics of Structures 1, and in particular the success rate of passing a second year subject Thermodynamics 1. This subject is widely seen as one of the most challenging subjects to Mechanical Engineering students in the early part of their course. This paper further presents the result of a teaching methodology that has been trialled in the second year subject Thermodynamics 1 with the student group that started their course in 2004

Commencing Student ENTER scores

The distribution of ENTER scores for students attempting Mathematics 1, Physics 1 and Mechanics of Structures 1 were compared for the 2004 and 2005 commencing student cohorts, each with about 200 students. The ENTER score results for all three subjects were very similar so only the distribution for

Mathematics 1 is presented here. As shown in Figure 1, significantly more students in 2005 now fall into the 70 to 80 ENTER bracket. Swinburne has always had a significant intake of students from TAFE graduates as well as mature-age entries which explains the student group with a lower than 80 ENTER for 2004 and those below 75 in 2005. Swinburne attracted a larger percentage post-95 ENTER students in 2005 whereas the population of 90 to 94 ENTER students is smaller for 2005.

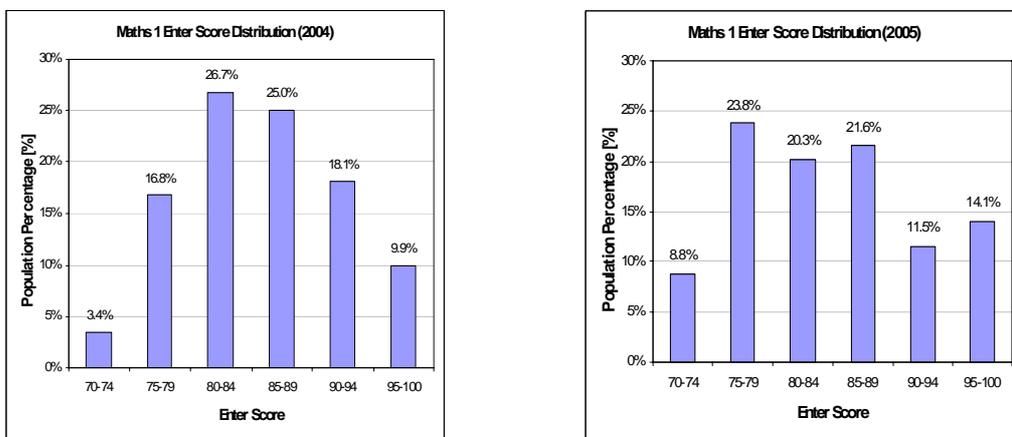


Figure 1. Student ENTER score distributions for Mathematics 1 (2004 and 2005)

The Effect of Lower ENTERS

It is extremely difficult, if not entirely impossible, to produce a reliable correlation between ENTER scores and subject results since the results depend on many more variables; e.g. especially human influences, part-time work, gender, ethnicity, socio-economic background and the difficulties associated with being from non-English speaking backgrounds. However, it can clearly be seen in Figure that there is definite upward trend between ENTER scores and examination results, albeit a very weak correlation. The net effect of the larger group of lower ENTER students can clearly be seen in the results in Mathematics 1 between 2004 and 2005 as shown in Figure 2. Similar findings were obtained by the Oregon University System when examining the retention, attrition and graduation of their engineering freshmen (North, 2003). In addition, Abdel-Salam (2005), found that there was only a small correlation between GPA (similar to ENTER) and university success.

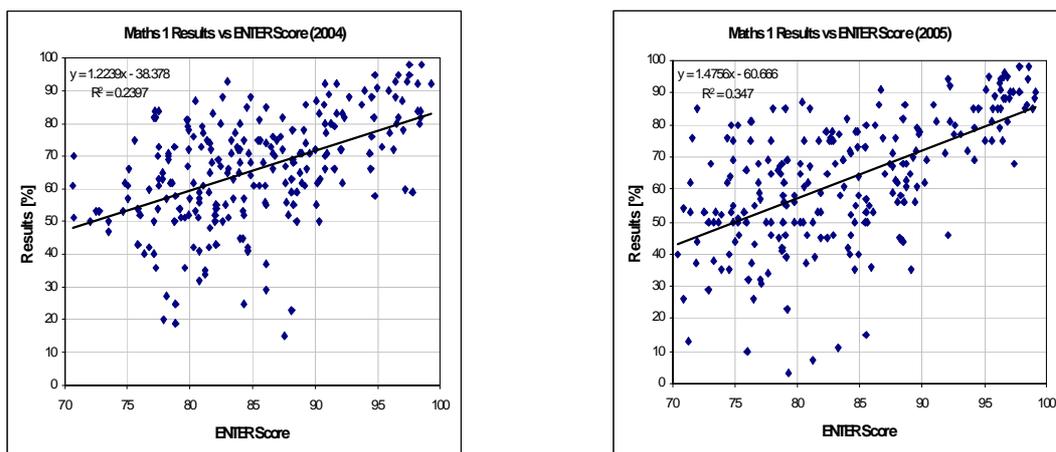


Figure 2. Student results for Mathematics 1 (2004 and 2005)

It may be interesting to note that the slopes of the least squares fits were similar for all three subjects and both years of investigation (i.e. for Physics: 1.17 (2004) and 1.19 (2005), Mechanics of Structures: 1.2 (2004) and 1.18 (2005)). In all cases a larger percentage of students fall in the lower ENTER region.

From the data shown in Figure 2 for Mathematics 1, several important conclusions can be drawn (the other two subjects have almost identical results):

- The scatter of the examination results becomes much greater at lower ENTERs. This implies a much greater level of uncertainty in the success of students in this group. However, it is also clear that there is a significant portion of students in the 70 to 80 ENTER band that has performed very well. Some of these students were found to have articulated from TAFE or are mature age entries. Hence, ENTER score alone is clearly not a reliable indication of student performance.
- Very few students with ENTERs lower than 80 managed to obtain distinctions (75% and above) or high distinctions (85% and above – only 3 students in 2005). Hence it appears that it will be a significant challenge to lower ENTER students to really excel in their studies (at least in the first year of study) and thus it presents a great challenge to a university to transform these students into really excellent students and eventually excellent engineers.
- It is very rare for a 90 ENTER student to fail. But for a few exceptions the same can be said for 85 ENTER students.
- It appears that that the results scatter (and hence the risk) becomes very large for enter scores below 80.

When considering the pass and failure rates for Mathematics 1, shown in Figure 3, the failure rate (N) has increased notably from 2004 to 2005. As a consequence the pass rate (P – 50% and above) has decreased and likewise students who achieved credits (C – 65% and above). The percentage of distinctions (D – 75% and above) have almost remained the same. The slight increase in high distinctions (HD – 85% and above) is explained by the increase in post-95 ENTER students in the 2005 intake. Thus as expected, a larger intake of low ENTER students will inevitably result in more failures.

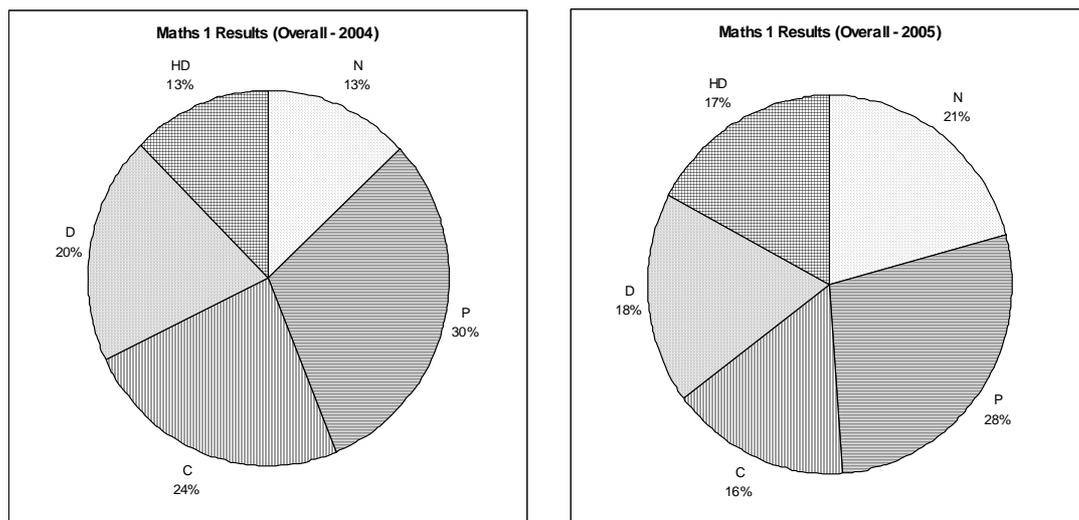


Figure 3. Student result distributions for Mathematics 1 (2004 and 2005)

It is clear from the results of the three subjects investigated that the reduced ENTER requirements have negatively impacted on the overall performance of students. It is not always possible to predict outcomes based on ENTER scores, or GPA/SAT scores (Abdel-Salam, 2005). A real challenge therefore faces institutions with ENTER requirements below 80 or even 85 to prevent failure rates from increasing substantially, or even endeavouring to reduce failure rates.

The Thermodynamics 1 Experiential Learning Project

Since the introduction of the ENTER system, Swinburne's ENTER requirement remained around the 80 mark, varying from 80.3 in 1999 to 82.05 in 2001 and 80.5 in 2004. For this period of time the authors have taught the subject of Thermodynamics 1 to second-year students. Thermodynamics 1 is widely seen as one of the most challenging subjects to Mechanical Engineering students in the early part of their course. Concepts such as entropy and exergy are hard to grasp and students find it challenging to bring theory and practice together.

Homework problems in many subjects, including Thermodynamics, are often meaningless and boring to students. As a result students may complete a problem without having any real understanding of the validity of the results obtained. Quite often, textbook questions are formulated in such a way that students are expected to calculate a single result – for example what the power output of a certain gas turbine cycle would be. These types of problems do not foster a habit of analysis and understanding with students as the answer is merely a number. As such, they will often complete problems using textbook examples as templates and hence even arrive at correct answers without any physical understanding of the science the problem is supposed to illuminate!

The subject lecture delivery was exactly the same as in previous years; however the requirements for the tutorial classes, assignments and class tests were overhauled. The changes that were made are as follows:

- **Scheduling of tutorial classes.** The subject is delivered through lectures, tutorial classes and laboratory classes. For this project, the tutorial classes were scheduled such that they lagged one week behind the lectures in terms of the curriculum. This allowed students the opportunity to work on homework problems for a week to discover problems and formulate sensible questions for the tutorial classes. The laboratory classes were scheduled about two-thirds through the semester. This allowed the delivery of enough theoretical material to enable students to understand the concepts at hand, yet it allowed students to experience a practical application of the theory taught in the curriculum close to the point of delivery.
- **Regular assessment and feedback.** It is common knowledge that many failures in the first and second years of study occur mainly because students fall behind the study schedule. In many cases they are not able to catch up at a later stage. The solution to this problem is obvious (regular class tests), however many lecturers discard this option because of the large increase in workload that will be incurred. A system of short tests (10 minutes maximum) at the start of the weekly tutorial classes on the previous week's subject material was introduced. At the conclusion of the tests they were collected and redistributed to be marked by fellow students – the marker adding his/her name to the marked test sheet. This afforded students the opportunity to get immediate feedback on mistakes made and the identification of subject material not well understood. The opportunity therefore existed to deal with such material during the same tutorial class. The results were added to the online learning system (Blackboard, 2005) the same day so that students can monitor their progress throughout the semester. Furthermore, the weekly tests ensured that most students did indeed do some homework between the lectures of the previous week and the tutorials of the following week.
- **Fortnightly computer-based assignments** in the form of design tasks, parametric- and uncertainty analyses. One of the largest single contributing factors to the increase in success was the introduction of computer-based assignments. Students were introduced to an excellent computer package Engineering Equation Solver (EES, 2005) which is extremely simple to learn and use and is ideally suited for the modelling of simple engineering systems. In particular, EES is extremely well suited to do parametric studies (what-ifs) as well uncertainty analyses. Moreover, since it is unit-aware, student quickly learn the importance of unit consistency in their calculations. It is also able to perform most of the mathematical functions that are encountered in engineering problem solving such as integration and differentiation.

Experiential Learning Implementation

The main purpose of subjects such as Thermodynamics is not first and foremost to impart subject knowledge to the student – they will promptly forget the subject details after the final examination, but to train students in the fine art of engineering analysis, problem-solving, synthesis and design. The employment of an engineering simulation and analysis software package such as EES has proven to be instrumental in overcoming these problems. Students were given the normal amount of homework problems each week. On average about two weeks were spent per chapter. At the conclusion of each chapter therefore, a problem from the textbook that is a good representation of the subject material was chosen as a computer-based assignment. Instead of simply asking students to solve the problem on computer, which would simply result in yet another meaningless number as the solution, they were taught instead to create a

computer model of which the inputs could easily be modified. The students then performed parametric analyses to investigate the influence of some independent variables on the system performance. These influences were then plotted which allowed students to visualize the interdependencies of variables. Two examples of analysis and implementation are given.

- **Example 1.** In the first example the students were given an assignment where they had to investigate the influence of the boiler pressure in a steam Rankine cycle on both the cycle efficiency and the power output. By varying the boiler pressure in a parametric study, they soon discovered that whilst an increase in pressure will theoretically result in increasing cycle efficiency, increasing the pressure beyond 42 MPa results in a decrease in power output because of the decrease of the enthalpy of evaporation at those high pressures. Hence they discovered the principle of the law of diminishing returns as well as the concept of an optimum pressure that is to be determined by maximising both power and efficiency. They learned that in the real world of engineering, trade-offs between competing parameters are a rule rather than an exception. Furthermore, they were also asked to investigate the influence that uncertainties would have on cycle efficiency and power output. It often escapes the minds of many students that any given input data for an engineering model carries with it a certain degree of uncertainty. They therefore had to analyse the system performance sensitivity to the combined influences of the given uncertainties. Students are often amazed at the findings when some parameter has an unexpected influence on performance (whether large or small). Ultimately though, their understanding of the wider world of engineering is enhanced.
- **Example 2.** In a second example they were asked to investigate the financial viability of a proposed hydroelectric scheme where water is pumped to a high level reservoir during night time by buying electricity at discounted prices (Figure 4). The flow direction is then reversed during peak day time hours, selling electricity at a higher prices and hence generating a profit. Not only did they need to model the system through the relevant engineering calculations, they also had to analyse the system's financial viability and ultimately express an opinion on the feasibility of the scheme from an investor point of view.

This assignment was by no means trivial. Several technical complications were added to the problem. They had to find the most profitable operation level of the top reservoir via a parametric study. Furthermore, the pump and turbine efficiencies were provided as functions of reservoir height, as would be the case in reality. Additionally, uncertainties in pipe length, reservoir height, pump and turbine efficiency, pipe roughness, the purchase and selling price of the electricity and the flow rate were also specified.

Having completed this assignment, students not only had a solid understanding of the relevant engineering equations, but they also understood the interdependencies of parameters and the influence that uncertainties have on the system as a whole. They could therefore identify critical parameters that required more careful consideration during the design phase. They would also understand that best performance is a trade-off and that optimum values may exist. Finally, they would learn how each parameter contributes to the financial viability of the venture.

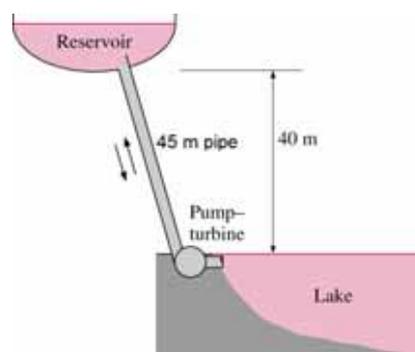


Figure 4. Typical computer-based assignment- illustration of proposed hydroelectric scheme where water is pumped to a high level reservoir during the night (Cengel and Cimbala, 2005)

For the above example, Figure 5 shows the results of a sensitivity analysis which indicated that the turbine efficiency (η_t : 33.59%) is much more important than the pump efficiency (η_p : 9.20%). This conclusion is extremely important since the same turbo machine serves as a pump during the day and as a turbine during the night. Hence the machine could potentially be a more efficient turbine than pump or vice versa. The student will now understand that given these choices, it is obvious that the best machine choice should favour turbine efficiency and not pump efficiency. The student would also have discovered that the pipe roughness and length are not significant and can be compromised. Lastly, they had to contemplate the financial feasibility of such a system in practice and calculate the return-on-investment and provide an in-depth discussion on their findings. From the results they learned that the selling price of the electricity or more critical than the purchase price and hence negotiations should focus on the selling price.

Variable ± Uncertainty	Partial derivative	% of uncertainty
hourly profit overall = 148.7 ± 53.65 (\$) (highlighted)		
$\varepsilon = 0.00036 \pm 0.0001$ [m]	$\partial \text{hourly profit overall} / \partial \varepsilon = -10790$	0.04 %
$\eta_p = 0.855 \pm 0.0855$ [-]	$\partial \text{hourly profit overall} / \partial \eta_p = 191.1$	9.20 % (circled)
$\eta_t = 0.9 \pm 0.09$ [-]	$\partial \text{hourly profit overall} / \partial \eta_t = 346.8$	33.59 % (circled)
$L = 45 \pm 5$ [m]	$\partial \text{hourly profit overall} / \partial L = -0.3824$	0.13 %
price _{buy} = 0.15 ± 0.015 (\$/kWh)	$\partial \text{hourly profit overall} / \partial \text{price}_{\text{buy}} = -1089$	9.20 %
price _{sell} = 0.4 ± 0.04 (\$/kWh)	$\partial \text{hourly profit overall} / \partial \text{price}_{\text{sell}} = 780.3$	33.59 %
V _{ol} = 2 ± 0.25 [m ³ /s]	$\partial \text{hourly profit overall} / \partial V_{\text{ol}} = 57.23$	7.06 %
$z_{1,\text{base}} = 40 \pm 4$ [m]	$\partial \text{hourly profit overall} / \partial z_{1,\text{base}} = 3.600$	7.10 %

Figure 5. Results of a sensitivity analysis which indicates that the turbine efficiency is much more important than the pump efficiency (*Engineering Equation Solver (EES, 2005)*)

As demonstrated above, this type of assignment ensures a much more realistic, interesting and instructional way of doing homework problems than the traditional method of solving a problem with pen and paper, often arriving at meaningless answers. It encourages lateral thinking and entrepreneurship and demonstrates to students a typical engineering approach to solving problems.

Usage of an online learning system (Blackboard)

Another major contributor to the teaching success of Thermodynamics 1 has been the use of the online learning system – Blackboard (2005). Since assessments were done on a weekly basis and assignments on a fortnightly basis, student feedback was updated up to twice per week. Students were able to monitor their progress regularly and had ample warning if they were not meeting the required standards. Furthermore, the Blackboard system was used to submit assignments and even hosted a discussion forum. The discussion forum allowed students to get help online from lecturers, tutors and fellow students, even after hours. The high degree of communication amongst students was evident in the “discussion forum” section of Blackboard and was considered to be an interpersonal active approach to experiential learning.

Industry visits

The learning process is greatly enhanced by visualisation. In Thermodynamics 1 a class tour to a coal fired power station forms the highlight of the course. Students find it an awe inspiring experience and a great source of inspiration. The experience gained by physically seeing boilers, turbines, mills, the control rooms, cooling towers, smoke stacks and a large dredge operating in an open cast mine cannot be reproduced in a classroom or even a laboratory. Students generally gained a much deeper appreciation of the theory and are more able to bring theory and practice together.

Outcomes of the Experiential Learning Approach

The results for the subject, as far as pass-rate is concerned only varied marginally during this period. However, the results for 2005 show a 15% improvement on the average pass-rate of the previous years. On average, students have achieved substantially higher marks than in previous years. The success of the new Experiential Learning approach in terms of overall student pass rate is shown in Figure 6.

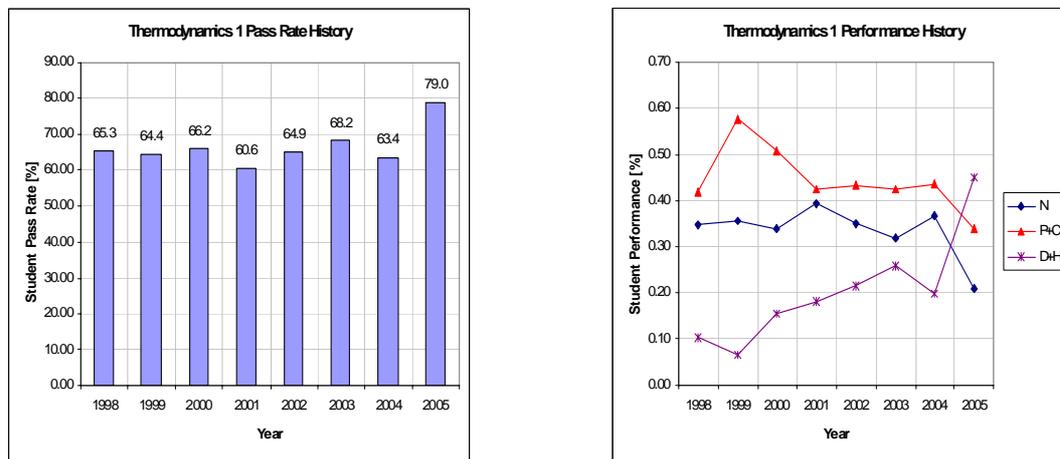


Figure 6. Student pass rate history for Thermodynamics 1

It is evident that the pass rate History remained fairly constant from 1998 till 2004. This is also evident from the line graph (Figure b) where the failure rate (N) remained reasonably constant up to 2004. However, in 2005 a 15% increase in the pass-rate was achieved (Figure a). Furthermore, from Figure b it is important to notice that a 25% increase in the number of distinctions and high distinctions (D+HD) was achieved over the previous year. The corresponding decrease in the students achieving passes and credits (P+C) indicate that a substantial portion of students from this group have now performed with distinction. The 2005 student group in Thermodynamics 1 consisted of 65 students, and roughly the same numbers were enrolled in previous years.

Student Attitudes and Perception Changes over the Course of the Subject

Student perceptions and attitudes were surveyed twice during the course of the semester for all 65 enrolled students. The first survey was conducted 4 weeks into the 12 week semester. The second survey was conducted in week 12 of the course. The change in survey results between week 4 and week 12 showed a definite growth in the development of maturity of students, as illustrated by changes in the students' perceptions of (Figure 7 to Figure 12):

- The reasons why they fell behind during the semester
- The subject workload (as perceived at that stage of the semester, and whether they can cope with it or not)
- The course content and its aims
- Teaching quality
- Contribution of lectures (as compared to tutorials) to the learning process
- Assessment and feedback (class tests, laboratory reports and assignments) and feedback

Student perceptions of the reasons for falling behind during the semester (Figure 7). Several important conclusions can be derived from these results:

- A significantly larger portion of students (8% more) were up to date in week 12.
- A larger percentage of students correctly identified laziness and poor time management as primary causes of falling behind.
- The disinterest shown by some students has been cured at the end of the semester.
- Almost three times more students realised that their part-time work contributed significantly to a lack of study time.
- No students cited poor teaching as a cause.
- Originally half of all students felt that the workload was too high. Less than a quarter of the group still held this view at the end of the semester. This indicates a significant improvement in student maturity towards the subject.

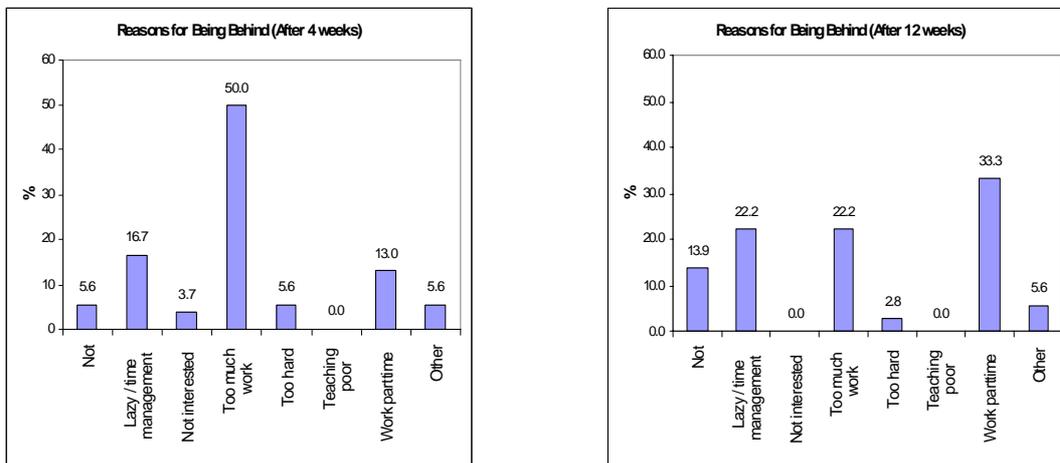


Figure 7. Student perceptions of the reasons of falling behind

Student perceptions of the subject workload (Figure 8) indicates that a substantial percentage of students have changed their opinions on the high workload level of the subject. At the end of the semester about 16% more students felt that the workload was within their capabilities and expectations for the subject. Even though the overwhelming majority of students still felt the workload was much higher than they feel comfortable with, most of them did not see the workload as impossible at the end of the semester as was shown in Figure 7 for week 12.

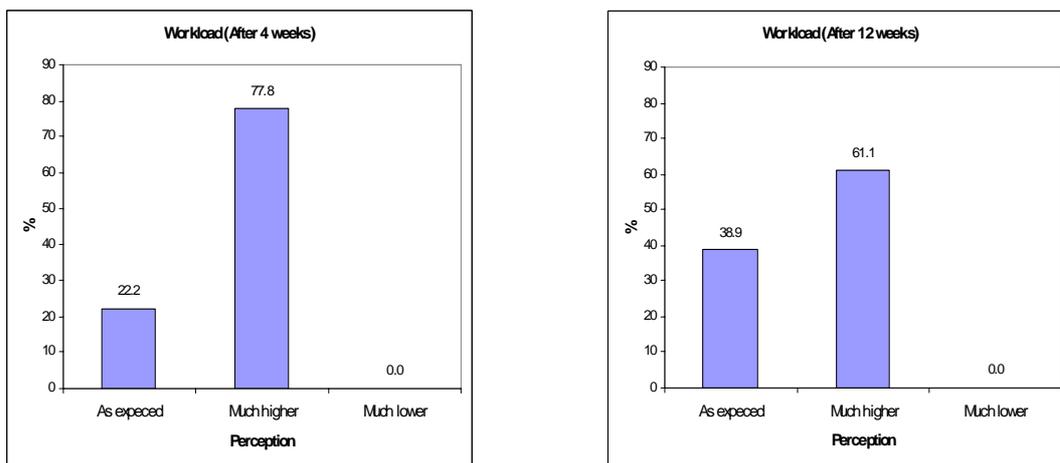


Figure 8. Student perceptions of the subject workload

Student perceptions of the subject curriculum (Figure 9) also indicated a large positive shift of student opinion. Initially, almost half of the class thought that the key to success was to rely on the memorisation of subject material instead of logical thought processes. This view is shown to have dramatically changed by the end of the subject after 12 weeks. This is perhaps the most significant achievement of the subject as a whole and highlights the success of the experiential learning process employed.

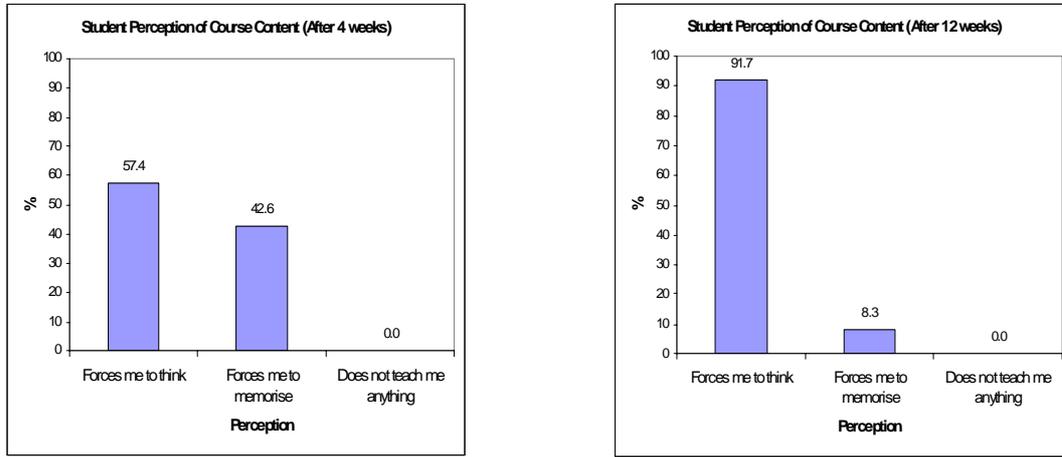


Figure 9. Student perceptions of the curriculum

Student perceptions of the teaching methodology (Figure 10) show another dramatic shift. Initially students were much less inclined to appreciate the newly introduced experiential learning methodology. However, it is quite clear that most students eventually were very much persuaded by its merits.

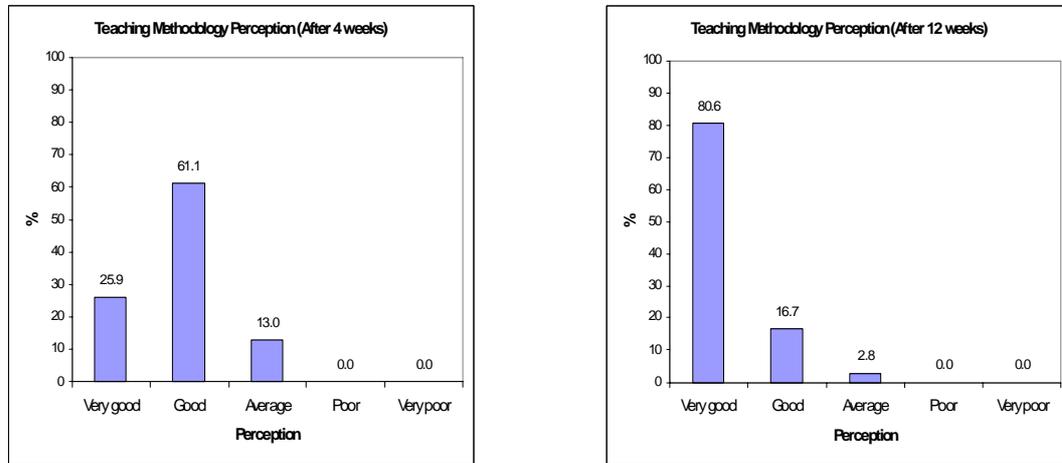


Figure 10. Student perceptions of the teaching methodology

The student perceptions of the value of lectures in the learning (Figure 11). Initially most students indicated that they were not able to gain much understanding of the subject material during the formal lectures. This is a significant problem in many technically challenging subjects. Students generally find it hard to cope with subject material in the lectures. As a result they mostly disengage during lectures and put their hope in the tutorials as the sole opportunity for formal learning. The ideal situation however is that students are able to digest the principles during lectures, then attempt homework problems in their own time and use the tutorial sessions the following week as the final opportunity to sort out those questions that they could not manage at home. This approach would also foster the required skills all engineers need for lifelong learning throughout their careers. As Figure 11 shows, great progress has been made in achieving this goal.

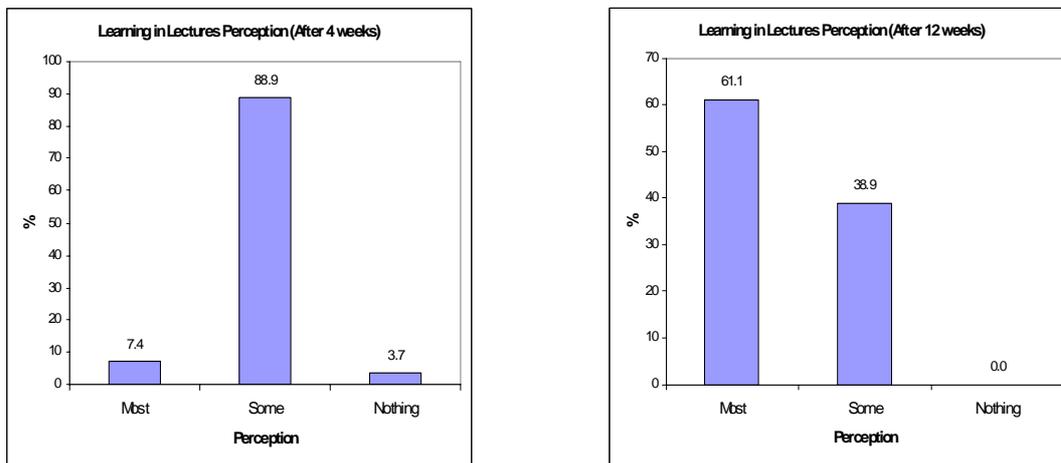


Figure 11. Student perceptions of the value of lectures

Lastly, the student perceptions of the quality of assessments and feedback (Figure 12) have also shown a noteworthy improvement through the course of the semester. Whereas almost half of all students initially thought that the assessments and feedback were fair to poor, less than 20% retained that view at semester's end. Approximately 80% showed a positive appreciation of the assignment, project and class test based assessments and the constant weekly feedback on Blackboard.

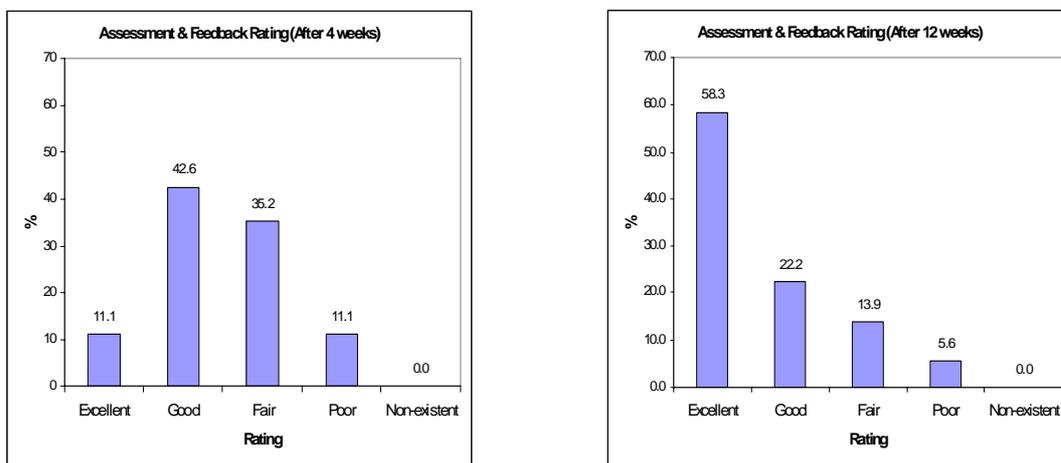


Figure 12. Student perceptions of the assessments and feedback process

Conclusions

It is possible to improve student performance significantly through the application of a suitable experiential learning program in some engineering subjects. It was demonstrated that student abilities were improved substantially as shown by the much improved pass rate. Their attitudes towards high workloads at the end of the semester were much more favourable than at the start. The overwhelming majority of students came to the conclusion that the best approach to mastering technical subjects such as Thermodynamics 1, was to develop the appropriate thought processes and that memorisation was of little value. Students were able through the assignments and other assessments to develop the ability to digest the subject material effectively during the lectures instead of only the tutorials. Lastly, students came to a real appreciation of the experiential learning process. With lower ENTER score entries inevitable for many universities, experiential learning is shown to be effective in improving the success rate of students in technical subjects such as Thermodynamics 1.

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