

Some considerations for the sustainability of engineering education

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***Abstract**: Engineering education in Australia and around the world is facing many challenges and there are justifiable concerns about whether it can be sustained in its present form and with current funding levels. The purpose of this paper is to discuss areas of concern and suggest possible ways forward. The main areas causing concern are increasing student/staff ratios, frequent reviews and course changes, lack of pre-requisite knowledge by students, cost of laboratories and uncertain funding. The need for increased efficiency is discussed and the means of achieving this.*

***Keywords**: engineering, education, sustainability.*

Introduction

The concepts of sustainabilty are normally applied to engineering practice such as design, development, production and maintenance. However, there are pressing reasons for considering sustainabilty in the context of engineering education. This is because many tertiary institutions have seen a great reduction in their funding relative to the number of students. At the same time many institutions teach in much the same way as they did ten years ago and are therefore not more efficient than they were. Compounding the problem the last ten years have seen an increase in "accountability" that has been manifested by frequent reviews. These in turn have inevitably led to course changes as no review is likely to conclude that no changes need be made. As an example consider the Department (now School) of the authors. In the last 5 years there has been a review of Engineering that resulted in major changes to the courses, an IEAust accreditation visit, a review of the Department and about to take place an Australian Universities Quality Audit Review.
In 1999 the Department had 20 teaching staff and currently has 14 with no reduction in student numbers. It might be thought that the Department's finances should therefore be healthy. In fact there have been no funds available for buying equipment (other than computers) for several years. At the same time the various reviews "encouraged" more project work in the lower years so that each staff member has an additional (on average) eight projects to supervise in each semester in third year. These activities are not efficient in staff time though it is not disputed that such projects are beneficial to most students. Thus there is less funding and teaching loads are significantly higher. Finally there is no indication that there will be any increase in funding levels, rather they may reduce further in real terms. The

question is therefore relevant, "Is engineering education sustainable?". The areas of concern will be discussed in more detail and then some suggestions on what may be done will be made.

Areas of concern

The main areas of concern of the authors are considered below. In different institutions there may be other more particular and local issues. Also the student intake may be very different and bring other issues. However, it is expected that those discussed below will be of general interest.

Student/staff ratios

One of the authors has been teaching at universities since 1972. During this time student staff ratios have continually increased. Many universities have very large first year classes (>500 students) and yet in subsequent years have very small classes because of the range of options/electives that are offered. Thus first year classes are regarded as a financial bonanza that helps fund the smaller higher year classes. This does however overlook the fact that first year students often need more attention and struggle with the transition from school to university.

The inevitable conclusion has to be that staff cannot spend as much time with individual students as they once did. Staff do not get to know students and are perceived as distant and not interested in the students. It is therefore not easy to spot students at risk, either of failing or with serious personal problems.

Frequent course changes

The time spent by academics on preparing good material depends on the length of time that the material will be current. If an academic is in charge of a unit for a significant time (say five years) then the unit may be developed to a high degree. There is the problem of the teacher becoming stale but the stability of teacher and content helps justify time spent on producing good teaching materials.

In recent times the need for "accountability" has resulted in numerous reviews that often result in course changes. The possibility of having the same lecturer teach an essentially unchanging unit for five years is becoming a distant memory. The consequence is that with other increased demands on time (eg. more students) very little effort is put in to producing good materials. For those few staff who attempt this there is soon a loss of heart at the small reward for a lot of effort when the material is no longer used.

Students' prior knowledge

Both of the authors have extensive contacts with first year engineering students. All first year students at UWA take a unit Engineering 101 which has material on statics, dynamics and dimensional reasoning. For many years we conducted a test without warning in the second lecture of a similar but now discontinued unit. The test used was the Mechanics Baseline Test (Hestenes 1992) which consists of about 30 multiple choice questions on basic mechanics. The results of one such snap test are shown in Figure 1.

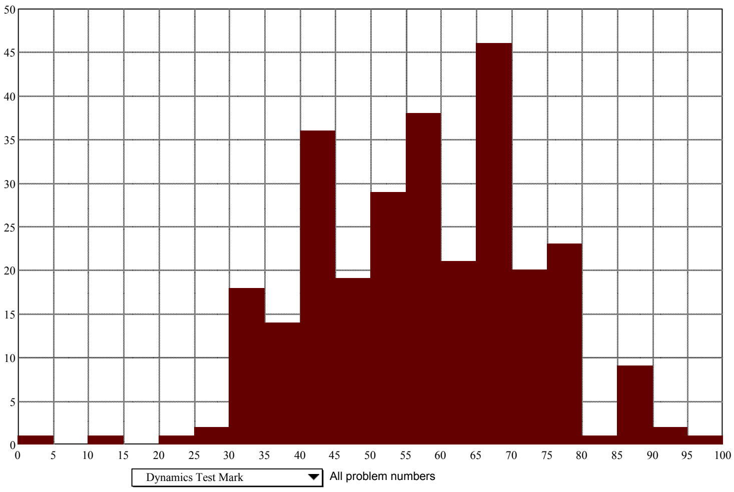

Figure 1 Mechanics Baseline Test scores from a snap quiz in a lecture, Feb 1999.

It was alarming to find that, though the students had all achieved high marks in their school leaving exam on Physics, 20% of the class scored under 40% in this exam. This result has several possible explanations.

* The students may not have been taught the material though this is extremely unlikely.
* The students never understood the material and the exam questions did not probe their understanding.
* The students crammed for the exam, knew sufficient on the day, but had no continuing knowledge of the material.

Whatever the explanation a first year lecturer has to accommodate what students know sitting in the lectures. This is becoming an increasingly time consuming task and students can feel "lost" very early in a unit. The question of how to determine if pre-requisite knowledge is present and what to do to rectify any shortfall demands time that is in short supply.

As an aside, our students' performance on the Mechanics Baseline Test was quite similar to that of first year students at Harvard, where the test was developed.

Laboratories

In a previous paper we wrote,

> "One of the major changes in engineering education that has occurred over the last forty years relates to laboratories (hereafter called labs). Stone remembers, as a student in the 1960's, undertaking 3 labs a week and each one required a report. Today both the number of labs and the amount of writing have been reduced. There appear to be several reasons for this. Lab hardware is expensive - there are not sufficient funds for major pieces of equipment such as turbines. The student/staff ratio is low in a lab and it is hard to justify such "inefficient" teaching in the current tight financial conditions. Any academic who develops new and innovative labs is unlikely to be rewarded. Labs do not count for much in promotion applications. There is therefore little incentive to focus on labs.... The use of virtual labs has been increasing." (Turnbull 2001).

Nothing has changed and engineering students are completing fewer labs and many of those are virtual labs. It is the experience of the authors that students do not have basic skills. As an example many students in third year did not know how to measure the frequency of oscillation of a torsional vibration. Engineers need hands on experience of real equipment.

Possible solutions

It may be thought that little can be done. For many academics that might be true since their teaching loads and other demands on their time do not allow the possibility of investing effort in looking for solutions. However the authors have been able over several years to make significant and time saving changes to the way they teach.

More efficient teaching

We have been using computer based tutorial systems in large first year engineering classes since 1995 (Scott 1999). Networked, monitored tutorial systems were fairly unusual when we started but are now quite common. Some features of our approach, however, are still not widely used:

* Our tutorial problems are somewhat diagnostic. When a student enters an incorrect answer, the computer system tries to give some feedback that may be helpful. We implemented this part of the system in a very simple way, by having each problem calculate both a correct answer and also a range of common wrong answers, from the randomised problem parameters. The maths for the wrong answers was developed by talking to students, by looking at past exam papers, and through long teaching experience.

  Why is this efficient? Because anything the computer system can help a student with is something that does not require human intervention.

* We run a messaging system called The Forum as an integrated part of the tutorial system. Some design decisions about the behaviour of The Forum have proven to be very helpful. For example we have structured the "discussion threads" so that there is exactly one thread per problem in our large problem set. This has worked very well because when a student is stuck on a particular problem, there is usually some quite specific discussion in the bulletin board for that problem. If the existing questions and answers are not helpful, a student can always post a new question at the end of the existing ones. Staff give such messages a high priority because The Forum is a very efficient form of teaching. A question posted by one student in a class of 500 – and the response from staff – can be viewed by all other students in the class. A given question need only be answered *once*! So the small staff effort to make answers swift and cogent is justifiable.

* Each year we must book tutorial times for our large first year class in a shared computer room called the Maths Computing Laboratory. It is a large hall with 128 web browser terminals. The tutors – mainly academic staff – do not dominate the room but instead wander about giving assistance. By observing the way that students actually work we have achieved some efficiencies. For example we do not generally book tutorial hours in the afternoon because students have historically not attended. They prefer to work in the morning. So we put up to three tutors into morning sessions and reduce the total number of tutorial hours. We respond to demand on a weekly basis and can move tutors if very full classes are seen.

This form of tutoring was designed to produce better outcomes but has had the added bonus of reducing tutoring time compared to the smaller group tutorial. We save up to 70% on tutoring time with better outcomes and higher student satisfaction.

Sharing of materials

It has been pointed out that there are about 30 universities in Australia with first-year dynamics courses. Most use one of two common (and excellent) textbooks but there is also usually some additional course material: a set of printed notes, a web site, or perhaps some on-line tutorial problems. In principle some of this teaching material could be shared between universities. Why does this rarely happen in practice?

This problem has, rather unkindly, been called the “not invented here” syndrome. Academics do have an independent streak but that is not the sole driving force behind the continuous re-invention of course materials.

We think there are two main reasons. The first is that university teachers are not generally suffering from a *lack* of teaching materials. This need can arise as a result of course revision but what is then needed are teaching materials *adapted* to match the new course. The degree programs at the 30 universities are all somewhat eclectic so the teachers are unlikely to find a set of course notes that is exactly right. First-year students, likewise, do not generally suffer from a lack of course material. What they need and desire, really, is *more contact with staff* to help them understand the material they already have.

In the case of tutorial problem sets there is the related problem of software compatibility. If two universities both have the same tutorial system, eg. WebCT, in theory the staff can share problem sets. But more often the software is not identical and it is not trivial to re-implement a problem set.

The other reason course material is not often shared is the problem of quality control. Our experience is that a single error in an assessed problem on our computer tutoring system causes a cascade of student worry and loss of confidence in the whole tutorial system. Students quickly begin to attribute all lost marks to system errors. This has a knock-on effect on overall class performance because if confidence in the tutorial system fails, morale also drops. If UWA agrees to swap a problem set with Griffith University, as an example, and assuming that the compatibility issue is resolved, what can we do if the set we receive is unsatisfactory? Or what can they do if our problem set has weak diagnostics or there are gross errors?

Because it is likely that continuous course review and revision will occur at all universities, we cannot expect long term congruence between any two courses at any two universities. Perhaps the best we can hope for is not cross-sharing but cross-injection of fragments of course material. At a given instant in time it may be possible for two staff at two universities to swap certain problems or notes. If the material is adapted and inserted into the canon of course resources at each site, there is some chance that the material will survive several course revisions, and thus realise an efficiency. However it should be noted that this is all dependent on the two universities having a flexible approach to intellectual property.

On-line laboratories

It seems that the cost of developing new laboratories and the lack of recognition (in promotion) of those who develop them will mean that little can be done. At UWA we have however found a means of developing new laboratories as part of an investigation of the use of on-line laboratories. Thus the development of such laboratories is part of the project work of students. We thus "kill two birds with one stone". At the same time such laboratories can be used off-line in a more conventional way.

The future of on-line laboratories is uncertain but there are clear advantages for students who are unable to attend labs on campus. Also it is possible that very expensive labs could be made available to other universities. In a previous paper the issue of the importance of hands-on laboratories was discussed (Turnbull 2001). An assignment was set requiring students to discuss the use of on-line labs and they were given the opportunity to be both in the lab and on-line. It was notable that all students indicated that the lab was essential to the full understanding of the unit (on vibration) and that the change from being on-line to seeing and touching the "real thing" was significant.

Stable course content, (and the problem of changing server packages)

There have been many changes to our tutoring system since 1995. There was a review and inevitable reconstruction of our first year program in 1999 (implemented in 2000). Also, because of changes to computer systems we have had to re-write our server package three times. Despite all these changes, however, we have been able to preserve some valuable results of previous work. Our dynamics problem set, written by Stone in 1994, has been preserved. The intellectual effort of devising good problems, and the associated diagnostics, has been repeatedly “ported” to new computer platforms and “recycled” as part of new courses.

This highlights two efficient activities: writing good problem sets, and porting/recycling. The two are linked because if the technology required to enable a good problem set is *too sophisticated*, it may not be feasible to port it to a new server platform or recycle it into a new course topic.

As a case study, at our university many staff are now using the commercial package WebCT. Anyone writing teaching material for WebCT will work with the existing, supported problem types such as multiple choice. Although not terribly useful in engineering, at least this problem type is simple enough that it should be easy to port a given problem set to some other package. In our case we rejected multiple-choice very early on and instead have concentrated on problems with numerical answers and diagnostics. These are not supported by WebCT nor, as far as we know, by any of the five or more other commercial tutorial systems. We have only been able to preserve the investment of time in our problem set because *we are also in control of the software development of the required server systems*.

Our message here, really, is “do not be afraid to write your own server package” if you want to have a unique interface for students. Writing a server package commits a staff member to a certain amount of yearly maintenance but gives independence from arbitrary institutional decisions, and allows preservation of unique problem types and other teaching development work.

Better links with schools

The problem of students not having pre-requisite knowledge is being overcome by the abundance of WWW based material. Thus within our school we are able to refer students back to what they were supposed to have covered. In some cases we just give a reading list based on WWW material to fill in the omissions. It therefore seems that a similar approach could be used if school material was similarly available AND the university lecturer was aware of it. However this is another time consuming process and it may never come to the top of the list of things to be done.

Conclusions

This paper has raised concerns about engineering education that question whether it is sustainable. At the same time some suggestions that may help have also been made. As is frequently the case individual lecturers will prioritise their tasks and act accordingly. We have been able to introduce new methods of teaching because our university encouraged us to do so and we work well as a team. We have the greatest sympathy for those lecturers who feel very alone and without support. The next decade will be of great interest as changes will be made/forced. It is an open question whether engineering education is sustainable in its present form and with its current financial constraints.

References

Hestenes D and Wells M (1992), "A Mechanics Baseline Test", *The Physics Teacher*. No 30, 159-165. See also http://modeling.la.asu.edu/R&E/Research.html

Turnbull, M. J. and Stone, B. J. (2001). 'The Importance of Laboratories in Student Understanding'. AaeE Conference 2001, 480-485.

Scott, N. W. and Stone B. J. (1999). 'We did it our way - and you must do it yours', KeyNote paper, AaeE Conference, Adelaide September 1999. *Australasian Journal of Engineering Education*, 8(2), 99-123.