Teaching Engineering

All you need to know about engineering education but were afraid to ask

Peter J Goodhew

The School of Engineering's Active Learning Lab at The University of Liverpool

The Higher Education Academy
UK Centre for Materials Education

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Foreword

This book is aimed firmly at the practising teacher of engineering at undergraduate or taught postgraduate level. Physical scientists ought to find a lot of it relevant too. It is intended to be based on clear research evidence and to explain as clearly as possible what the educational terminology actually means for the lecturer. I recognise that the vast majority of university teachers want to do a good job for their students but feel that they do not have the time (or sometimes the inclination) to study the literature on engineering education. However they ought to feel that the quality of their teaching should be as high as the quality of their research, and this means being familiar with its background literature. This book is intended to help. It offers critiques of the available learning and teaching techniques, bringing out the main advantages and disadvantages and explaining what might be involved in deploying each of them successfully. I also assume that you know a lot more about the technical content of your field of engineering than I do, and that you are both enthusiastic and fully briefed on the importance of engineering to society. You will therefore find no extended rationale for educating engineers and no attempt to define or specify particular curriculum content, which will differ among the engineering and science sub-disciplines.

Although the main text is largely jargon-free, a number of important educational terms are explained so that readers can, if they wish, follow the literature given in the references and bibliography.

A book like this cannot always give answers, but it tries to ask good questions and to make you think about your teaching. If you find and adopt one new idea into your teaching, or question one conventional practice, then my effort in writing will have been repaid. I have consciously tried to present a wide range of views and to provoke thought and debate. The greatest evidence of success that I can hope for is that, provoked by something I wrote, you start a debate in your common room or coffee bar.

If you started teaching in a UK university since 2000 you will probably have taken a part-time qualification in teaching. You may therefore be familiar with many of the major educational movements and concepts, although you are unlikely to have been exposed to critical commentary on them from an engineering academic.

I have taught engineering and science in UK universities for more than 40 years, have been responsible for the development of novel e-learning resources and was for many years the Director of the UK Centre for Materials Education. I have also had, in parallel, a conventional career in research in my technical discipline (electron microscopy) and have written half a dozen books on this subject before attempting my first volume on education. I hope you enjoy it.

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Terminology

There are many alternative terminologies in use around the world. In this book I will as far as possible adopt the conventions current in the UK: A discrete credit-bearing element of teaching, often with an associated examination or other assessment, will be called a *module*. In other countries this might be known as a course, a class or a unit. A coherent set of taught elements (usually modules) which leads to a qualification such as a degree, will be known as a *programme*. Programmes which lead to a first degree such as BEng, BSc or BS will be called *undergraduate* programmes while those which involve teaching beyond first graduation (such as MScs) will be called *postgraduate* taught (pgt) programmes. The terminologically anomalous UK degrees MEng, MSci and their equivalents are known as 'integrated masters' degrees and usually combine, within a 4-year programme, a first degree and a taught Masters degree. They are often treated as *undergraduate* degrees.

The organisational grouping within which taught programmes are delivered might be called a Department or a School, or occasionally a Faculty or Division. I will generally use the single word School to mean any of these.

Attribution and citation

I have found it very difficult to pin down the originator of many of the ideas I include in this text. I claim no credit for any of them except those prefaced by 'in my experience' or some similar phrase. I would like to give proper credit and acknowledgement to all those whose original work I have represented or mis-represented, but despite the apparent power of the internet it is often only possible to locate an anonymous extract or an un-named report. I apologise now to anyone I have omitted to credit fully. I would appreciate being told of the original reference in every case – if you have it, please email me.

> 'The reasonable man adapts himself to the world, the unreasonable one persists in trying to adapt the world to himself. Therefore, all progress depends on the unreasonable man.' George Bernard Shaw. I therefore hope to be unreasonable and Shavian!

Peter Goodhew [goodhew@liv.ac.uk], September 2010

How to use this book

It's short – you could read it right through, ignoring the material in boxes unless they particularly excite your interest. There are two types of boxed text: One consists of questions or comments you might like to consider – I don't know the right answers, although I might have some views. The other boxes contain elaborations of topics in the text, and references to help you find out more if you need to.

If you have a particular task or purpose in mind, then try the following short cuts:

Your interest	Where to look
I have to develop a new module	Chapter 5
I have to develop, or revise, a whole new programme	Read it all
I want to improve assessment of a module or programme	Chapters 5 and 6
I want an overview of the current state of engineering education	Chapters 2, 3 and 8
I am reviewing a whole programme as an external advisor	Chapters 1, 2, 3 and 7
I am concerned at the poor results students are achieving in my module	Chapters 5 and 6
I am concerned at how poorly-prepared students are when they arrive for my module	Chapters 1 and 4
I have a feeling that I could teach my module better	Chapters 5 and 6
I need some evidence that changes in teaching would be worthwhile	Chapter 6f
I feel that our system needs to change, but I am finding it difficult	Chapter 7

Glossary

ABET	Accreditation Board for Engineering and Technology (US) [www.abet.org]
AMS	Accreditation Management System (Australia) [www.engineersaustralia.org.au]
CDIO	Conceive, Design, Implement, Operate, an international movement for the reform of engineering education [www.cdio.org]
HEA	The Higher Education Academy (UK) [www.heacademy.ac.uk]
HEFCE	The Higher Education Funding Council (UK) [www.hefce.ac.uk]
JISC	The Joint Information Services Committee (UK) [www.jisc.ac.uk]
LO	Learning Outcome
OSCE	Objective Structured Clinical Examination
QAA	The Quality Assurance Agency (UK) [www.qaa.ac.uk]
PBL	Problem Based Learning
PDP	Personal Development Plan (or Planning)
PjBL	Project Based Learning
PLE	Personal Learning Environment
UKCME	The UK Centre for Materials Education
UK-SPEC	The UK specification for accreditation of engineering degrees [www.engc.org.uk/professional-qualifications/standards/uk-spec]
VaNTH	Vanderbilt, Northwestern, Texas and Harvard
VFM	Value For Money
VLE	Virtual Learning Environment
WBL	Work Based Learning

Chapter 1: The purpose and context of engineering education

A question: What is engineering? What differentiates an engineer from a scientist?

Introduction

There are many reasons for encouraging people to learn about engineering, and therefore there is no unique meaning for the phrase ‘Engineering Education’. In this chapter some of the main motives for teaching engineering will be explored. The remainder of the book will tend to focus on just one of the implied tasks – the preparation of students for a career as a practising professional engineer. However many of the techniques which will be discussed are applicable whatever the intended outcome for the student. Notice that already a piece of educational jargon has almost crept in: The phrase ‘learning outcome’ will be defined in *Chapter 2*.

It might be helpful to clarify what engineering education (in the context of this book) <u>is not</u>. It is not about the acquisition of specific practical skills, however useful or interesting they might be to any individual. It is not about training people to run CFD codes or send CAD designs to a CNC machine or to grow crystals or to sign off structural steelwork. It <u>is</u> about the conceptual, planning and design skills which should precede all these activities. It is about imagining and understanding and predicting, as quantitatively as possible, why and how an engineering objective can be realised and delivered. It is not about how to cut the teeth on a gear wheel; it is about deciding on the number of teeth and their shape and understanding why (if at all) this gear wheel is essential to the proper functioning of the device. If indeed the device itself is necessary.

In the UK, the USA and education systems based on these two models, engineering education is usually focused on generic skills and understanding which can be applied in a range of employment environments. This is reflected in degree titles such as Mechanical Engineering rather than product-specific titles such as Tractor Engineering which used to prevail in (for example) Soviet societies [e.g. Tractor Engineering at Moscow State Technical University, or the Department of Road-Building Machines at Belgorod State Technical Academy of Building Materials]. However recent instances of skill shortages in key industries have led to the development of a small number of dedicated programmes such as railway engineering.

An interesting sidelight on engineering is provided by the US National Academy of Engineering report written in 2008 entitled Changing the Conversation [National Academy of Engineering, 2009]. This contains the comment: ‘… current messages are framed to emphasize the strong links between engineering and just one of its attributes – the need for mathematics and science skills. In other words, current messages often ignore other vital characteristics of engineering such as creativity, teamwork and communication.’ You will find this view is reinforced by many innovative practitioners of engineering education. In a detailed survey following the publication of this report, Pawley [2009] found that academic engineers (i.e. those of us who teach it) see their discipline as being about three things: applied science and mathematics; solving problems, and; making things. One of the questions we should ask ourselves is ‘do we expose our students to enough of the second and third of these?’

Even within the context of ‘education’ as defined above, there are at least four motives for providing an education in engineering.

a. To prepare students for research

Only a minority of engineering graduates will embark on a research career (indeed this is a very small minority in most cases). Nevertheless I consider this educational motive first because of the prominence (and current dominance) of research in many Departments and Schools of Engineering in Europe, Australia and the USA. The career success and reward of many engineering academics depends on their research output, usually measured by the two proxies of grant income and refereed publication. This environment drives academics in two particular ways: They are encouraged to believe that research is hugely important and that their teaching should be ‘research-led’ (although many would be hard pressed to articulate what this means in practice); Their success as researchers is facilitated if they have a ready supply of able and research-minded graduates eager to undertake doctoral study and post-doctoral employment. It is therefore in their self-interest to stimulate undergraduates to aspire to a research career.

A comment: Few of the students in your classes will want the same career as you. [On the other hand you should not feel any need to apologise for your noble choice of career!]

b. To prepare graduates for employment in engineering industry

This is the ‘obvious’ intention of both undergraduate and taught postgraduate programmes. The implication is that all students aspire to become professionally recognised engineers (‘Chartered‘ or ‘Incorporated’ in the UK context, ‘registered’ or ‘certified’ in some other countries) in one or more engineering disciplines. However there are number of less obvious points: The range of potential employers is extremely diverse and not all employers of engineers are ‘engineering’ companies; not all students will on graduation either choose (in good times) or be able (in bad times) to make use of their engineering skills. I have heard it argued that the higher the perceived standards of the School the more attractive their graduates are to non-engineering employers. At times fewer than half of the graduates of some very good Schools choose to deploy their engineering skills, opting perhaps for an initial career in finance or the law. If these career paths are foreseeable by students part-way through their programme, then this must influence their motivation towards and commitment to professional engineering.

c. To prepare engineering/science/numerically literate citizens for society

Many of the decisions which must be taken in a 21st century society involve an assessment of technical issues and/or quantitative data. An obvious example is the use of nuclear power for electricity generation: A proper approach to key decisions in this area involves an understanding of the technical possibilities and an appreciation of risk. How is it possible to take a view, and potentially vote on the basis of this view, without an understanding of the nature and effects of radioactivity, of the possible methods and contributions of electricity generation, of the reasons for and implications of energy use and global warming? Graduates of a science or engineering discipline are well placed to take an informed view whereas other members of society are much less likely to be able to adopt a rationally justified position. The production of such graduates is therefore a very worthy objective for engineering education, although it is rarely articulated in the vision or mission statements of Schools of Engineering.

d. To provide an intellectually stimulating education

> Education is a process involving two sets of participants who supposedly play different roles: teachers who impart knowledge to students, and students who absorb knowledge from teachers. In fact, as every open-minded teacher discovers, education is also about students imparting knowledge to their teachers, by challenging the teachers' assumptions and by asking questions the teachers hadn't previously thought of.
>
> [Jared Diamond in 'Collapse' (2005)]

There was a time when the primary purpose of a university degree programme was what we might now call 'general education'. The experience was intended to challenge students to think, rather than to accumulate specific knowledge or skills. This motive still survives in many Arts and Humanities disciplines and is still passionately championed by quite a few universities around the world which offer, for example, a 'great books' programme [e.g. St Johns College, and Shimer College (affiliated with the University of Chicago and contiguous with Illinois Institute of Technology) both in the USA, http://www.stjohnscollege.edu/academic/main.shtml and http://www.shimer.edu/]. There is no reason why a degree programme centred on engineering or science should not offer a similarly challenging and rewarding experience. One of the implications of such an approach is that the content or subject matter is of only secondary importance compared to the skills involved in understanding or interpreting it. And of course any programme designed to encourage thinking has to have *some* subject matter. Why should it not be related to engineering or science, rather than poetry, politics or philosophy? The Thayer School at Dartmouth College has a mission which meets some of these aspirations. Founded in 1867 by Sylvanus Thayer, the School is one of the USA's oldest professional schools of engineering. Thayer believed that engineering in the context of a liberal arts education could provide the single best preparation for addressing the world's problems, and this remains at the core of Thayer School's educational mission. Undergraduates are grounded in the liberal arts and rooted in the humanities. Their engineering sciences major is part of the Dartmouth Bachelor of Arts program, and many of them integrate their engineering work with other sciences or even studio art. [http://engineering.dartmouth.edu/about/index.html]

I could happily construct a technically-based Great Books programme. It would include *Collapse* by Jared Diamond, Marshall McLuhan, *Future Shock* by Alvin Toffler, one of Richard Dawkins' books, James Lovelock on Gaia, David King and David MacKay on climate change, ….

With such a diversity of potential graduate outcomes, is there a set of attributes which characterises (or should characterise) a graduate? Is it meaningful to speak of 'graduateness' – a phrase which enjoyed a few years of popularity around the turn of the 21st century? [QAA, 2007]

If we look in the UK Subject Benchmark Statement for Engineering, or UK Spec (the UK professional accreditation specification), or ABET (the US equivalent), we find statements such as:

> 'An approach to threshold standards based upon the mastery of a set (or sets) of defined elements of content would seem to be unattainable.'
>
> [QAA, 1997]

> 'In order to operate effectively, engineering graduates thus need to possess the following characteristics. They will be rational and pragmatic, interested in the practical steps necessary for a concept to become reality. They will want to solve problems and have strategies for being creative, innovative and overcoming difficulties by employing their knowledge in a flexible manner. They will be numerate and highly computer literate, and capable of attention to detail. They will be cost and value-conscious and aware of the social, cultural, environmental and wider professional responsibilities they should display. They will appreciate the international dimension to engineering, commerce and communication. When faced with an ethical issue, they will be able to formulate and operate within appropriate codes of conduct. They will be professional in their outlook, capable of team working, effective communicators, and able to exercise responsibility.'
>
> [Engineering Benchmark Statement: QAA, 2006]

> 'Chartered Engineers are characterised by their ability to develop appropriate solutions to engineering problems, using new or existing technologies, through innovation, creativity and change.'
>
> [UK Spec; Engineering Council, 2008]

'Student outcomes include:

a) an ability to apply knowledge of mathematics, science, and engineering;
b) an ability to design and conduct experiments, as well as to analyze and interpret data;
c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
d) an ability to function on multidisciplinary teams;
e) an ability to identify, formulate, and solve engineering problems;
f) an understanding of professional and ethical responsibility;
g) an ability to communicate effectively;
h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context;
i) a recognition of the need for, and an ability to engage in life-long learning;
j) a knowledge of contemporary issues; and
k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.'

[Proposed harmonised criteria: ABET, 2009]

What paragons we must already be producing! But how hard it is to specify the necessary learning outcomes in detail, and to measure (that is, assess) them. To take but one example from the lists above: How might we check that our graduates demonstrate 'an ability to identify, formulate and solve engineering problems'? You possibly reckon that you know this ability when you see it, but could you be more specific? How would you define a graduate-level problem? How does this differ from a masters level problem? How do you assess 'solve' for an open-ended typical engineering problem?

A rather simpler description of graduateness might be 'ability to be an independent learner', coupled with – ideally – a strong interest in engineering!

There are two further factors which we should consider at this stage.

e. The changing nature of university student generations

Educators cannot, on their own, define and control engineering education because (at least in non-centrally-directed societies) it is necessary for students to sign up before an offered programme can be viable. It matters not whether we call them 'Generation X or Y' or 'Millennials' or 'digital natives' or even 'binge drinkers'; The background, attitudes and expectations of students are changing increasingly rapidly. Each generation grows up in a different technological environment, in a different economic climate and according to different social mores. Engineering education cannot stand aside from these factors, even if we believe that many of the fundamental concepts and practices of our chosen profession are relatively timeless. It has to be the business of engineering educators to motivate students to engage with modern engineering and to relate their offered programmes to the contemporary environment, both in content and style.

We should also take to heart the words of Mark Prensky [2001]: ‘It is amazing to me that in all the hoopla and debate these days about the decline of education … we ignore the most fundamental of its causes. Our students have changed radically. Today’s students are no longer the people our educational system was designed to teach.’ Prensky gives a specific example of the difference this can make: ‘A group of professors came to his company with CAD software they had developed. College students were finding it difficult to master so they wanted to explore making it into a game. The professors wanted to teach the various skills in linear fashion and had made movies of five to ten minutes to illustrate various points. They were persuaded to inject faster pace, shorten the movies to 30 seconds, allow random rather than step-by-step access to the tasks and jettison written instructions. The game was a huge success and students engaged with concepts they had previously found too difficult.’ [Gwen Goodhew, 2009]

f. The prior knowledge and experience of 21st Century students

Long, long ago in the mists of the 20th century it was possible to assume that students presenting themselves to university engineering Schools would have constructed models using Meccano, could wire a plug for mains electricity (and would have received a 110 or 240V shock), had changed and mended the tyre on their bike, would have taken apart a clock and might even have taken off the cylinder head of their, or their parents’, car. Today none of these things is likely, although equivalent students might have keyboard skills and might have added more RAM chips to their laptop. There are two basic reasons for this – modern attitudes to safety, and the increased complexity and miniaturisation of everyday devices, leading to the black-box syndrome. The modern student cannot (almost literally) learn much from opening the back of a digital watch, or clicking together Lego, or opening the bonnet of the family car to reveal a plastic filter cover embossed with the maker’s name. No gear wheels, spark plugs or even nuts and bolts, are easily visible. All the engineering, both clever and mundane, is hidden within a ‘black box’. This paucity of practical experience of engineering must diminish the almost subliminal store of knowledge and understanding which the student brings to the beginning of his or her studies. He has every excuse for not knowing how a Hard Drive recorder or an iPod nano works – they have no visible working or moving parts. Realisation of this inevitable restricted level of engineering experience dictates that educators must make substantial efforts to provide an engineering context – almost an explanation of what engineering is about – to first-year students.

A question: What can your students do that you couldn’t at their age?

The number of the factors described above, and their multiple combinations and interactions, mean that there can be no single ‘engineering education’ which is fit for every purpose. A well-designed curriculum must surely involve compromises and at best can only be biased towards a particular graduation outcome, based on some knowledge of the experience and aspirations of the incoming students. Part of the necessary compromise arises from the realisation that many students will change their intentions, their attitudes and their motivation as they progress through their programme.

We've been here before.

It is instructive (or possibly depressing) to realise that many issues in engineering education have been around a long time. The following paragraphs are reproduced unchanged from the preface to a study of engineering education sponsored by the Carnegie Foundation in 1918, almost 100 years ago [Mann, 1918].

> 'Fifty years ago … the engineering course … was four years. The first two were spent mainly in the fundamental sciences – chemistry, physics mathematics and mechanics; the last two years mainly in the application of these sciences to theoretical and practical problems. In the half century which has passed this course of study has been overlaid with a great number of special studies intended to enable the student to deal with the constantly-growing applications of science to the industries.
>
> While the original teaching plan remains as the basis of the four-year engineering curriculum, the courses given in most schools have been greatly modified in the effort to teach special subjects. As a result, the load upon the student has become continually heavier and bears unequally in … different parts of the course. In addition there is a widespread feeling that under this pressure the great body of students fail to gain, on the one hand, a satisfactory grounding in the fundamental sciences; and on the other hand do not fulfil the expectations of engineers and manufacturers in dealing with the practical problems with which they are confronted on leaving the engineering schools.
>
> … engineering education will never be satisfactory until theory and practice are taught simultaneously. …
>
> It is an interesting fact that while much is said about the teaching of science in the modern school, the methods of teaching science are but little changed from those employed in teaching the subjects that filled the curriculum before the teaching of science began in the school.'

I would not need to change many words to update this message to 2010!

What you might take away from this chapter:

- The question ‘what (and who) am I providing this engineering education for?’;
- The realisation of the need to continually assess and understand the experience and attitudes of incoming students;
- An understanding of the importance of explaining to incoming students, with examples, the significance and role of science and engineering in society.

Students displaying their design work in the Active Learning Lab at Liverpool

Chapter 2: Some educational background

To generalise grotesquely, engineers - although well accustomed to open problems with multiple potential solutions - like their experiments and theories to be based on quantitative analysis and hard numbers. Unfortunately this is rarely possible in education, where outcomes are hard to measure numerically or repeatably, and where control groups are difficult to come by. Nevertheless a number of pedagogic conclusions and 'models' have gained currency. I will state their main findings in plain language and refer the reader who needs more detail to the panels. [Note: we usually refer to the study of how education works, and how students learn, as *pedagogy*. Strictly this is a misnomer, since pedagogy refers to how children learn, and we are usually dealing with adults. Andragogy has been suggested as a better word for the study of the learning of adults, but it does not seem to be catching on.]

David Ausubel was a cognitive learning theorist active in the 1960s and 70s. I don't suggest that you need to read his work, which is, for our purposes, over-psychological but you might take to heart his central message (which I paraphrase)

'Find out what the student knows and teach accordingly'

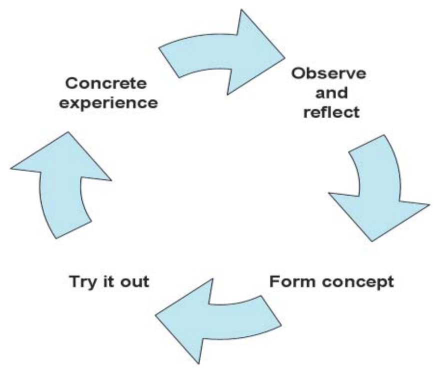
a. Some potential models are, for example;

We should make sure that we assess or examine what we want the students to know or be able to do, and then we should ensure that our teaching helps them to achieve this knowledge or develop the appropriate skill. This is known as ***constructive alignment***; and was championed by John Biggs [1999]. We need to deploy this idea when designing a new module, course or programme.

Constructive alignment is the idea, propounded by Biggs in 1999, that the curriculum should be designed so that the learning activities, and assessment of them, should both be aligned with the learning outcomes which the programme is intended to deliver. This sounds simple and obvious, but is quite a challenge to deliver. In devising the delivery of the curriculum, thought must be given to the most appropriate ways to help the student to learn, and this must be underpinned by a very clear understanding of what the intended learning outcomes really are. If you then add in the facts that not all students learn in the same way, and that staff will need to experiment because they won't get it right first time, you will understand that the task is genuinely 'open', having no single right answer. There is an extremely useful concise summary of Biggs' ideas, and how you might implement them, on the web site of the Engineering Subject Centre, extracted from the paper by Houghton (2004). I assume, in the following chapters, that constructive alignment is the ideal to which we are all working, although we may fall short in practice!

Many students of engineering learn best by having a concrete experience or making an observation, thinking about it (reflecting and perhaps suggesting a hypothesis or reason), attempting to relate this to an abstract concept and then conducting an experiment (real or imagined) to confirm or refute it thus refining their hypothesis and moving on to make a further concrete observation. This is known as the ***Kolb learning cycle*** [Kolb, 1984] and is the basis for most developments in the area of *experiential learning*. We need to bear this in mind when devising active or experiential elements of our teaching such as those described in *Chapter 5*.

The Kolb cycle



[After Kolb (1984)]

Many people have commented that they would like to develop understanding in their students, not just the ability to memorise or parrot information. This is referred to as the difference between ***deep and surface learning***. Marton and Säljö (1976), and subsequently Entwistle (1988, 2009) have written a lot about these learning styles. However lots of researchers have found that any given student can operate in both modes at different times and for different purposes. This is often referred to as ***strategic learning*** – doing what is minimally necessary to achieve the desired goal. You could argue that one of the tasks for a teacher is to persuade the student that her desired goal is understanding, and thus deep learning would be the best strategy.

Entwistle gives two characteristic descriptions by engineering students which clearly typify the difference between the deep and surface approaches (*see box on next page*).

Student comments:

Surface approach
'I suppose I'm mainly concerned about being able to remember all the important facts and theories that we've been given in the lectures. We are given an awful lot of stuff to learn, so I just plough through it as best I can. I tried to take it all down in the lectures, and then go over it until I'm sure they won't catch me out in the exam. ... (With the problem sheets) the first step is to decide which part of the lecture course the problem comes from. Then I look through my notes until I find an example that looks similar, and I try it out. If it doesn't work, I look for another example, and try a different formula.'

Deep approach
'It is not easy, you know. I'm not satisfied unless I really understand what we're given. I take quite full notes, but afterwards I go through them and check on things which I'm not sure about. I find that working through the problem sheets we're given is a good way to test whether I know how to apply the theory covered in lectures, and I do that regularly. Once you realise what lies behind the problems – that's the physics of it and what makes it a problem – then you can do them. You get a kick out of it too, when it all begins to make sense.'

[Taken from Entwistle (2009)]

The concepts of deep and surface learning need to be at the front of our minds when designing any new teaching or learning activity.

There is a commonly used series of levels of learning, called ***Bloom's taxonomy*** [Bloom, 1956]. It is most frequently presented in terms of six levels of understanding, starting with pure recall of facts from memory and culminating with a sufficiently deep understanding to be able to analyse, synthesize and predict. The levels are often described in terms of the verbs which could be deployed in testing achievement on the Bloom scale. Bloom is therefore useful when devising teaching approaches but comes into its own when developing assessment tools such as exams and assignments.

Bloom's taxonomy
This is a version of the taxonomy for the cognitive domain (i.e. about knowledge and understanding). Bloom proposed other taxonomies, in the affective and psychomotor domains, but they have not been so influential.

Level		Verbs which might be used in assessment
1	**Knowledge**	count, define, describe, draw, find, identify, label, list, match, name, quote, recall, recite, write
2	**Comprehension**	conclude, demonstrate, discuss, explain, generalize, identify, illustrate, interpret, paraphrase, predict, report, restate, review, summarize, tell
3	**Application**	apply, change, choose, compute, prepare, produce, role-play, select, show, transfer, use
4	**Analysis**	analyze, characterize, classify, compare, contrast, debate, deduce, diagram, differentiate, discriminate, distinguish, examine, outline, relate, research, separate,
5	**Synthesis**	compose, construct, create, design, develop, integrate, invent, make, organize, perform, plan, produce, propose, rewrite
6	**Evaluation**	appraise, argue, assess, choose, conclude, criticise, decide, evaluate, judge, justify, predict, prioritize, prove, rank, rate, select

[Bloom (1956)]

Those of us who have been teaching, and therefore writing exam questions, since the nineteen sixties or seventies need to notice that 'discuss' is only asking for a level 2 response and 'compare and contrast' is still only testing level 4 skills.

Engineering education is often described as being ***constructionist*** (or ***constructivist***) implying that learning involves constructing understanding from a number of smaller components. This construction can only be done by the learner, not by the teacher. 'I cannot learn for you, and you cannot learn for me'. The constructivist approach is implicit in Biggs' constructive alignment principle (*see above*).

In the previous paragraphs I have made much use of the word **understanding**, but this is a hard concept to pin down. I would not want to be quite as cynical as Johann von Neumann 'In mathematics you don't understand things. You just get used to them', but there is room for debate as to what either the academic or the student might understand by understanding. It must be true that for most academics, the more we know and understand, the more we realise that our understanding is incomplete or imperfect. A colleague once remarked to me that understanding is simply a re-definition of your problem in terms which you are prepared to accept without further questioning. Educationists would say that there is likely to be a difference between the 'target understanding' envisaged by the teacher and the 'personal understanding' achieved by the student.

What most commentators agree on, particularly in science and engineering, is that understanding needs to be based on knowledge – to understand, you must know some facts. Understanding then involves putting these facts into a context or framework with which you are comfortable, and preferably helps you apply your understanding to other situations and sets of facts. Students often comment on understanding as involving a feeling of satisfaction when insight emerges – either suddenly 'aha!', or gradually – and as delivering meaning and significance. This is of course not necessarily the same meaning or significance that the lecturer had in mind!

> A comment: You might not find it easy to determine whether some or all your students have understood.
> 'The one who understands does not speak; the one who speaks does not understand' Chinese Proverb

A related idea is the **threshold concept** [e.g. Meyer and Land, 2003]. This emerges from the observation that there are often particular sticking points in understanding which, when grasped, enable the student to make further progress. An engineering example might be the second law of thermodynamics. Once the student has 'got' this, much of the subsequent material becomes a lot easier, and understanding will have been advanced. The understanding of a threshold concept is likely to be transformative (it opens up new areas of the subject or casts new light on them), irreversible (you are unlikely to un-learn such a concept) and integrative (it usually helps to bring hitherto separate facts together). When teaching a subject it makes sense to identify the probable threshold concepts and then try to ensure, above all else, that these are understood by every student. You are then almost literally opening doors to future understanding (whatever that might mean!). See http://www.ee.ucl.ac.uk/~mflanaga/thresholds.html for a comprehensive set of references relating to threshold concepts, and Michael Flanagan's web pages for the use of such concepts in electrical and electronic engineering [http://www.ee.ucl.ac.uk/~mflanaga/#tal].

A further concept to bear in mind when attempting an explanation or trying to encourage understanding is that students find it easiest to understand an idea which is just a little bit beyond their current understanding, but not too much. Vygotsky (1925) called this their *zone of proximal development* but we do not need to rely on this phrase to understand that setting tasks which are too complex (far beyond the student's current grasp) or too simple (appearing to be already understood) is not inspiring and is unlikely to lead to effective learning – indeed in both cases it is likely to be de-motivating. The lecturer's problem is that anything you try to explain is unlikely to be in the current zone of proximal development for every student! Which is why you answer questions at the end of a session, or attempt to explain things twice, in different ways.

> A question: Is the learning of engineering necessarily linear? Are other approaches possible?

b. Learning outcomes (LOs)

Learning outcomes are the statements of the knowledge, understanding and competencies which our engineering programmes are designed to develop in our students. Most universities now demand that every module, programme or course has pre-defined learning outcomes, couched in phrases such as 'at the end of this module the student will be able to …'. One of the practical challenges for a programme director is to ensure that the LOs delivered by all the modules in the programme cover (but do not repeat too many times) the learning outcomes specified for the whole programme. This is straightforward in principle during the original design of a programme, but difficult to maintain throughout the subsequent inevitable changes of staff, modules and ideas. It is particularly difficult to maintain in the face of experimental changes in the teaching or assessment practices of individual lecturers, but without experiment nothing would change at all.

> UK-SPEC (the document against which UK engineering degrees are accredited) includes the following definitions of terms which might be used in specifying Learning Outcomes:
>
> - *Knowledge* is information which can be recalled;
> - *Understanding* is the capacity to use concepts creatively, for example in problem solving, in design, in explanations and in diagnosis (see also the discussion in a. above);
> - *Know-how* is the ability to apply learned knowledge and skills to perform operations intuitively, efficiently and correctly;
> - *Skills* are acquired and learned attributes which can be applied almost automatically;
> - *Awareness* is general familiarity, albeit bounded by the needs of the specific discipline.
>
> [UK-SPEC (2004)]

c. Background influences

Many professional and governmental bodies take an interest in the education of engineers. Accrediting bodies such as the Engineering Council in the UK (www.engc.org.uk, via UK-Spec), ABET [www.abet.org] in the US, and AMS in Australia [www.engineersaustralia.org.au/about-us/program-accreditation] appear to wield considerable influence over teaching (if not learning) in universities which offer engineering programmes. In this book I will not consider these influences further, except to comment that most accreditation bodies lag behind developments in teaching and learning and the sensible educator's approach to them might be to first develop pedagogically-sound, interesting and challenging engineering programmes and only then seek accreditation for them, in the knowledge that you have tried to do your best for the students. Why should such a programme be rejected?

A further set of influences is provided by the agreement among 45 or more European countries (the Bologna declaration) to harmonise the overall structure of university degrees. This agreement, whose first version was signed in 1999, initially attempted to harmonise the periods of time associated with learning at each stage of higher education. It originally posited a 3+2+3 structure, which implied 3 years of study to a Bachelor qualification, followed (if desired) by 2 years of study to a Masters degree and a further 3 years to a doctorate. It was not easy for all countries to adapt their education systems to this rather rigid pattern, and it was pointed out by many observers that the outcomes of each stage of education were far more important than the time taken. However outcomes are much harder to define (see the discussion of 'graduateness' above) and the Bologna process is slowly evolving via a continuing series of further agreements [in Prague, Berlin, Bergen and London]. The Bologna agreement has nothing specific to say about how we might teach engineering, so will not be considered further here.

In 1995 the Carnegie Foundation set up a body (subsequently known as the Boyer Commission) to review the Education of Undergraduates in the Research University (implicitly in the USA). Since much of engineering education is carried out in so-called research universities (even outside the US) it is worth looking at some of their, quite far-reaching, ideas.

> 'This report does not enter the continuing discussion of the content of the undergraduate curriculum – whether there should be more science, more mathematics, more foreign language, more anything – and it does not address the issue that has come to be labelled 'The Canon,' the body of writings deemed to be the requisite possession of the educated person. Those matters concern every institution involved in baccalaureate education. ' [Boyer report: Kenny, 1998]

The Boyer report (Kenny, 1998) proposed a Student Bill of Rights and made recommendations, of which a few are repeated (with occasional paraphrasing), here.

- '… students should be able to engage in research in as many courses as possible, … [and] must learn how to convey the results of their work effectively both orally and in writing;
- A student embarking upon a degree program at a research university should be adequately prepared to meet the intellectual challenges of that program; if remediation is necessary, it should be completed before entering the program;
- Every freshman experience needs to include opportunities for learning through collaborative efforts, such as joint projects and mutual critiques of oral and written work;
- The inquiry-based learning, collaborative efforts, and expectations for writing and speaking that are part of the freshman experience need to be carried throughout the program;
- … integrate major fields with supporting courses so that the program becomes an integrated whole rather than a collection of disparate courses [or modules];
- Academic majors must reflect students' needs rather than School interests or convenience;
- All student grades should reflect both mastery of content and ability to convey content. Both expectations should be made clear to students;
- Courses [modules] throughout the curriculum should reinforce communication skills by routinely asking for written and oral exercises;
- Faculty should be alert to the need to help students discover how to frame meaningful questions thoughtfully rather than merely seeking answers because computers can provide them. The thought processes to identify problems should be emphasized from the first year, along with the readiness to use technology to fullest advantage;
- Capstone courses appropriate to the discipline need to be part of every undergraduate program. Ideally the capstone course should bring together faculty member, graduate students, and senior undergraduates in shared or mutually reinforcing projects. [We might call a capstone course a final year project];
- School leaders should be faculty members with a demonstrated commitment to undergraduate teaching and learning as well as to traditionally defined research;
- The correlation between good undergraduate teaching and good research must be recognized in promotion and tenure decisions;
- A 'culture of teaching' within Schools should be cultivated to heighten the prestige of teaching and emphasize the linkages between teaching and research.'

And finally (you will like this one):

- 'Rewards for teaching excellence, for participation in interdisciplinary programs, and for outstanding mentorship need to be in the form of permanent salary increases rather than one-time awards.'

Notice the emphasis on student thoughtfulness, inquisitiveness, collaborative learning (which we might today call team or group work), on fluent and persuasive writing skills, and on enlightened leadership, as well as on research itself. This was pretty good stuff in 1998, and resonates well with our preoccupations more than a decade later [http://www.sunysb.edu/boyerreport]

d. UNESCO

The UNESCO Task Force on Education for the Twenty-first Century concluded in its reports in 1996 and 1998 that 'education throughout life is based upon four pillars: **learning to know, learning to do, learning to live together and learning to be.**' This analysis has been reiterated by such writers as Sir Graham Hills in the 1999 (UK) Foresight report 'The Future of the University'. Clearly this analysis is intended to apply to all education but it gives engineering educators plenty of material for thought. The first three pillars are, I would argue, essential components of a decent engineering education. Engineers have to understand how to educate themselves throughout their lifetime, they have to be comfortable doing things (not just thinking or writing about them) and their work is largely focused on society learning to live together (otherwise why would we bother about transport, energy conversion or high-speed communications?). 'Learning to be' is at first sight less relevant, but in the words of the UNESCO report, engineers should surely benefit from 'an education that equips them to develop their own independent, critical way of thinking and judgement so that they can make up their own minds on the best courses of action in the different circumstances in their lives'. [http://www.unesco.org/delors/fourpil.htm]

e. CDIO and similar movements

During the early years of the 21st Century the CDIO movement emerged from three Swedish universities and MIT in the USA. CDIO is a rather clumsy acronym for Conceive, Design, Implement and Operate. It is intended to emphasize the full range of any engineering discipline and was coined in response to a perception that engineering education had been developing into the teaching of engineering science only, in a contextual vacuum. CDIO adopters agree to set their education in the context of the whole continuum of engineering, recognizing that professional engineers are involved in identifying societal needs, in conceiving products and systems to address these needs, in manufacturing, operating, maintaining and properly disposing of their products as well as the 'core' disciplinary topics of design (in all its various forms). Adoption of CDIO as your context also implies that employers (industry and government) will be involved in the development, and possibly delivery, of your programmes.

At the time of writing, the CDIO movement has attracted 50 members across every continent except Antarctica, and the CDIO context has been adopted for programmes in many engineering sub-disciplines, including aerospace, mechanical, civil, computer, materials, electronic and also architecture. [Crawley et al (2009) and www.cdio.org]

f. VaNTH and How People Learn

A group of engineers at **Va**nderbilt, **N**orthwestern, **T**exas and **H**arvard Universities (including MIT) restructured their engineering programmes from about 2000 along lines suggested in the book How People Learn [Bransford et al 1999]. This involved what they call Challenge Based Instruction, which we can consider to be similar to Problem Based Learning. Note the American use of the word *Instruction*, which you almost never see in UK literature where the use of *Learning* has become dominant. (Does this indicate a difference of approach on the two sides of the Atlantic? I don't think so.)

A key set of ideas in the VaNTH approach is that instruction (or learning) has to be knowledge centred (you need some facts); student centred (it has to start from where the students are); assessment centred (everyone needs feedback on how they are progressing), and; community centred (learners need to feel that they are entering a community of practitioners – Chemical Engineers or whatever). A paper by Cordray et al [2009] summarises the effect of this approach in Bioengineering.

g. Other sources to read

A first port of call for ideas, definitions and resources should be the web sites of the UK HEA Subject Centres. All of these can be accessed, and searched, via www.heacademy.ac.uk. The two most relevant Subject Centres are Engineering (www.engsc.ac.uk) and Materials (www.materials.ac.uk) but it is always worth searching all Centres from the HEA site because there is a lot of expertise relevant to the teaching of engineering which can be gleaned from other disciplines. A further resource available to most engineering academics is the Educational Development Unit (or some similar name) operated by your university. This will be staffed with people who may not be engineers, but for whom much of the subject matter of this chapter is very familiar. They are generally only too pleased to be asked for their help – it's their job!

If you only ever look at one other book about education, I recommend Elizabeth Barkley's 'Student Engagement Techniques' (2010). It was published after I had written a significant portion of my own text and I found the first part of it so sensible that I almost stopped writing. I finally persuaded myself that Barkley was writing for a general audience, with no particular slant towards any particular discipline, so I could possibly still add value writing in the context of Engineering. However I have unashamedly included (with proper attribution) many of her ideas and comments in this text.

There are several other very readable books which have been influential in stimulating thought and debate about engineering education. Although the purpose of the current book is to minimise your need to consult them, you may find several of them interesting, particularly if you wish to follow up any of the ideas presented rather sketchily here. They also contain more of the evidence which supports some of my assertions. The volumes by Paul Ramsden ‘Learning to Teach in Higher Education’ and John Biggs ‘Teaching for Quality Learning at University’ are classics in the field. Diana Laurillard ‘Rethinking University Teaching’ is wise and knowledgeable about the use of technology in teaching. Noel Entwistle’s ‘Teaching for Understanding at University’ is a thoughtful analysis of what we have learned from educational research, written by an experienced researcher with a background in Physics. Graham Gibbs’ work at Oxford and elsewhere has been very influential – for example his ‘Teaching Students to Learn’ is short and pithy. ‘A Handbook for Teaching and Learning in Higher Education – Enhancing Academic Practice’ edited by Heather Fry and her colleagues contains, in 400 pages, articles on a variety of topics including small group teaching, and teaching of experimental science and engineering. The volume by Warren Houghton ‘Learning and Teaching Theory for Engineering Academics’ is a brief summary of what we have learned from educational research, while the books by Sheri Sheppard et al ‘Educating Engineers’ and Crawley et al ‘Rethinking Engineering Education; The CDIO Approach’ contain specific recommendations about the future of engineering education.

There are also several journals which publish research into engineering education. Among the most useful are the Journal of Engineering Education (published by ASEE – the American Association for Engineering Education – in partnership with a network of international engineering education organizations.), and the European Journal of Engineering Education (published by SEFI, the European Society for Engineering Education – strictly Société Européenne pour la Formation des Ingénieurs).

Last but not least you should read (or at least dip into) the Robert Pirsig classic ‘Zen and the Art of Motorcycle Maintenance‘ (1974). I was far too young to appreciate it when I first read it, shortly after it was published in paperback in 1976, but in my maturity I recommend it to anyone who wants to consider what a university is about. Read *Chapter 13* for a discussion of the purpose and nature of a university, *Chapter 16* for a passionate argument for the abolition of grading and degree classifications and *Chapter 22* for an enlightened discourse on why many of the laws and systems we use as scientists and engineers are *convenient* rather than *true*. In *Chapter 26* Pirsig presents the useful Japanese concept of ‘mu’ – the third answer to a question which was intended to elicit either yes or no. As I understand it, ‘mu’ might mean that the question is unanswerable or inappropriate (the wrong question to be asking) or that the answer is indeterminate. What a useful response to be able to give!

In *Chapter 28* you will find further reference to the ‘Great Books‘ programmes initiated at the University of Chicago, which I mentioned in *Chapter 1.*

Throughout Zen, Pirsig returns time and again to the idea of quality and the triple difficulties of defining it, teaching it and assessing it. I suggest that if this issue has not troubled you in your teaching, then you have not thought about it seriously enough. Read Pirsig and at least realize that you are not alone in struggling with the absolute measurement of quality. [QAA, and equivalent bodies outside the UK, please note.]

What you might take away from this chapter:

- The realisation that other academics have been thinking about how to educate engineers, and what is important for the graduate, for many years. We can learn a lot from work published in English in the UK, the USA and Australia and even from a novel;
- The recognition that there are a small number of really significant ways of thinking about learning and teaching. Among these are constructive alignment and learning outcomes, and the difference between surface and deep learning;
- The reassurance that there is a lot of support out there, ranging from books (several of which are quite sensibly written and easy to read), to people (for instance in the HEA's Subject Centres or belonging to the CDIO network) and of course your own colleagues.

A Meccano bridge, designed and made by engineering students, being put in place across a canal in Liverpool

Chapter 3: The current state of teaching

In this chapter I attempt to summarize what seems to be the normal student experience in the vast majority of the universities which are currently teaching engineering in 2010. In order to do this I have to generalise rather too much, but my conclusions are based on a number of pieces of evidence in the UK, Australia and the USA.

a. Contact hours and conventional teaching

Anecdotally the vast majority of engineering and science programmes, across the world, are ‘delivered’ (itself a word which implies teaching rather than learning) by means of lectures, tutorials and laboratory classes. A few detailed surveys of teaching methods (in Materials, Physics and Chemistry, Goodhew et al 2008; Edmunds, 2009; Gagan, 2009) have been carried out recently. They reveal that, apart from rare periods of intense project activity, students in engineering and science typically have about 20 scheduled ‘contact hours‘ per week – time in which they are encouraged (or mandated in some institutions) to be present at a specified time and place to undertake a pre-determined activity.

In most cases ‘contact hours‘ include lectures (typically ten or more per week), laboratory classes (ranging from 5 to 10 hours per week) and tutorials (usually no more than one per week).

In most programmes these timetabled activities account for the ‘delivery’ of most of the intended learning outcomes. However the contact hours are often supplemented by activities such as industrial site visits, research projects and, increasingly, team projects such as design-build-test exercises.

Most universities indicate an expected number of hours of study for undergraduate students which typically amounts to 40 hours per week during term-time. In principle, if students take this advice, they should be devoting about 20 hours per week to private study. This is likely to include the writing of assignments (either as essays or as the solution of problems), the writing up of laboratory results as reports, reflection on the week’s learning and further study from alternative sources. There is evidence to suggest that only a few students actually study for as long as 40 hours per week, at least in Europe and the USA. For example the UK Materials Subject Profile [Goodhew et al, 2008] reveals that students claimed to be devoting an average of ten hours per week to private study during their first year. In later years the average rose to 15 and then 25 or more in their final year. These are claimed, not measured, figures and they are only partially supported by two recent reviews of the student learning experience in UK Schools of Physics and Chemistry, which reveal that students devote about 7 hours per week to non-contact study in their first year, rising to about 11 in their final year. Academic staff expected students to do about twice this amount of study! [Edmunds, 2009; Gagan, 2009]

You might expect a student who is genuinely engaged in learning engineering to want to spend more than 40 hours per week on engineering-related activity. Think of it this way: If we schedule for a student 20 'contact' hours per week for about 30 weeks of the year, then we are committing about 10% of their waking time. If they spend another 20 hours a week on study (which the research quoted here indicates that most of them don't), this increases to 20% of their time. It should not seem a big ask that someone who is passionate about a subject would want to spend more than 20% of their time on it!

b. Innovative and less-conventional teaching methodology

Many – indeed probably most – undergraduate programmes in engineering and science include a small amount of non-conventional teaching and learning. It is common, in modular programmes, to find a small number of modules delivered via problem-based-learning (*see below and Chapter 5c*) or with varying amounts of active learning (*see Chapter 5f*). There are also plenty of examples of the use of technology to support student learning, although most of these are at a very elementary level – for example the use of a VLE (virtual learning environment) to store handouts or Powerpoint presentations for later study. These techniques are covered in more detail in *Chapter 5*.

Although such examples of innovation are to be found scattered within undergraduate programmes almost everywhere, it is extremely unusual to find a programme which has been designed and delivered based entirely on unconventional methods (i.e. not based on ten or more lectures per week).

It is worth trying to define some of the more frequently used terms in the area of less-conventional teaching and learning. Each of these is, regrettably but inevitably, imprecise and all of them are used in different ways by different authors and in different countries. With these caveats, my descriptions can be found in the boxes. Several of these topics are explored in more detail in *Chapter 5*.

Assessment can be **formative** (it helps the student understand) or **summative** (it results in a mark) or both.

E-learning usually implies the use of a computer to access material to help with learning. As I write, the terms TEL (technology enhanced learning) or ELT (enhancing learning through technology) are beginning to be more widely used. At its lowest level e-learning might simply imply the use of a VLE (typically based on Blackboard, WebCT or Moodle) to store lecture notes or Powerpoint slides. At a more developed level it might embrace formative or summative on-line assessment or offer support material for assignments. In its most developed form, e-learning should offer activities which cannot be offered by a handout, a book or a whiteboard. These might include detailed interactive simulations of engineering processes or virtual scenarios for teams of students to operate within.

The use of the terms e-learning or TEL by unsophisticated teachers may merely refer to the lowest levels of engagement – perhaps putting their notes on the institution's VLE. I find this use rather disappointing, when the power of true e-learning is in its ability to offer much more than previously-available techniques. However no doubt the situation is improving as I write. For a thorough and detailed exposition of e-learning I recommend reading Laurillard (2002), and *also see Chapter 5.*

Distance learning (DL) would appear to be uncontentious, but beware! DL is often used to imply e-learning, available at a distance, whereas it should merely mean learning at a distance, as most strongly typified by the Open University in the UK and several large on-line universities based in the USA. These institutions often use paper-based material as well as on-line or off-line CD-based materials. There is also an increasing appreciation that learning materials developed for use at an implied long distance (another city or country) can equally be used by local students who are merely not in your lecture theatre or classroom when they study it. The International Centre for Distance Learning at the Open University in the UK has a large database of literature on DL together with a long list of providers [http://www-icdl.open.ac.uk/: accessed 7/1/10]

Work based learning (WBL) is usually what it says it is – learning in the workplace. WBL obviously offers advantages in access to tacit knowledge, skills and know-how, and in reducing costs for the student. The issues here are principally with assessment of the learning outcomes and with accreditation of prior learning (i.e. learning gained before registration for the current programme). [Gray, 2001; Adams et al 2004]

Part time study. This seems to be obvious – it relates to students not attempting as many modules at one time as would be possible for a full-time student. However there are those who assert that most students are now 'part-time' in one or two senses: they may be working to earn money in parallel with their studies and/or they may be living at 'home' and enjoying the same social life as they had before enrolling as a student. This applies to the 18-21 age group as much as to older 'mature' students. Such individuals may not think of themselves as full-time students, embedded in the 'student lifestyle' but as members of their local society which will include friends at work as well as those studying. While in many ways this is very healthy, it may account for negative responses to a lecturer's suggestion of activities beyond the 'working day'.

Group or team working. Group work involves exercises undertaken by groups of, usually, between 3 and 8 students. Team working might imply that the groups are competing in some way, but is often used interchangeably with group working. Projects are often undertaken in groups but there are plenty of other learning activities which can take advantage of co-operative learning among a group of peers. Several of these are described in *Chapter 5.*

It is dangerous to assume that many aspects of working in a team will spontaneously occur to students. Some sort of training is thus highly desirable. It is debatable whether this is best reserved until after the students have had their first experience of working in groups and have therefore encountered some of the issues. It matters little, in my view, which semi-formal approach to teamwork is taken and it does not need to take very long. Some lecturers choose to expose students to the ideas popularised by Belbin (Team roles: Plant, Resource Investigator, Co-ordinator, Shaper, Monitor Evaluator, Teamworker, Implementer, Completer Finisher and Specialist) or Tuckman (Forming, Storming, Norming and Performing), or use a Myers-Briggs analysis of personalities. Look them up on the Internet for thousands of pages on any of these.

However it seems to me more important that this is done only once, in a consistent way, during an undergraduate programme. This requires a good oversight of the whole content of the programme – something which a Programme Director should in principle have, but may in practice be lacking. It is worth bearing in mind, as with a number of other topics, that your student cohort may contain individuals with widely differing experience of working together. It might be a good idea to exploit this experience during the teamwork training, to take full advantage of the pre-existing expertise.

Problem-based learning (frequently abbreviated to PBL) is a technique in which the students (usually in a group) discover for themselves the solution to a carefully-posed problem (Overton, 2005). They usually operate with the aid of a facilitator, who may or may not be an expert in the field (opinions differ on the relative merits of these two approaches). In working on the problem, students have typically to re-formulate the problem in terms they can understand and which help them reach a solution; devise an approach to a solution; discover, understand and interpret data, knowledge and concepts which are required; co-operate to develop their 'best' solution and present the solution (and possibly their thinking) to the facilitator or to others.

The PBL approach was adopted enthusiastically by medical educators in the period 1990-2010 to such an extent that the clinical aspects of the curriculum in many medical schools are now delivered almost entirely by PBL.

PBL has also been used extensively in science and engineering, although there are few examples of complete curricula delivered by PBL. PBL shares many characteristics with Project-Based Learning (*see Chapter 5*).

A recent study at my own university – an avowedly research-led institution – revealed that almost every student in Science or Engineering does encounter non-standard teaching, usually in every year of the programme. However these activities will, in almost every case, occupy only a small fraction of the student's time – they are the exception rather than the rule. 85% of the teaching staff appeared to offer no alternative to the 50-minute lecture and their only concession to 'innovation' was the use of Powerpoint and the mounting of their handouts on the local VLE.

c. Examples of radical change

Republic Polytechnic in Singapore has adopted an approach which is entirely based on PBL (problem based learning). Throughout its two-year Diploma courses in engineering it presents the students with a new problem every day [http://www.rp.sg/about/why_diff/index.asp]. Staff undergo substantial training (starting with a 5-day introduction) to help them act appropriately as PBL facilitators as opposed to lecturers – not something which we all pick up naturally.

They claim that this approach develops student-centred learning through 'self-directed discovery and questioning' and that critical reflection takes place throughout the learning process. These are splendid aims but there is as yet no evidence that Republic diplomates go on to become better graduate engineers. They certainly should.

A bold experiment in PBL was started by the University of Manchester School of Engineering in 2001. The whole of the first two years of the Mechanical and Aerospace Engineering programmes were devoted to PBL exercises and to long 'structured learning' sessions which were not lectures but might involve presentations of up to 15 minutes at a time. Early indications were that this approach improved retention and progression rates, motivated most (but not all) students and improved (but not to 100%) attendance rates. A major problem with the students was the persistence of a proportion of 'passengers', who contributed little to the learning of their peers. It was found (as with Republic Polytechnic) that staff training was needed to help staff cope with the role of facilitator (rather than teacher). Even so, many staff were not in favour of the new approach [http://www.engsc.ac.uk/er/features/pbl.asp].

Eight years later, in 2009, following a merger of Engineering Schools (UMIST and The University of Manchester) the wholehearted PBL approach has not survived, and their web site now states 'Typically, you take lectures and tutorial classes in the mornings with laboratory classes on some afternoons. Active learning is included in some programmes through a range of small problem based projects.' The PBL approach has not been lost, but has been seriously diluted. This is in contrast to many medical schools, where PBL was introduced sooner and still thrives.

The evidence for the success or failure of the PBL approach and PBL-trained graduates is sparse. This does not mean that PBL is unsuccessful; It reflects the fact that there is not a single undergraduate Engineering programme (in the UK at least) which offers a major PBL experience. Those universities which include PBL (and there are now quite a number of these) do so via a minority of modules and have been able to perform little analysis of their effectiveness. There is a review of the UK situation on the Engineering Subject Centre web site [http://www.engsc.ac.uk/er/features/pbl.asp]

A question: Does an understanding of engineering science have to precede the appreciation of engineering applications?

A large number of Schools of Engineering around the world have committed themselves to providing programmes in the CDIO context (*see above, Chapter 2*, for a description of CDIO, and also see www.cdio.org). The CDIO standards include the provision of an introductory module on Engineering practice, the offering of at least two complete design-build-test experiences to every student, the extensive adoption of active learning, team work and the integration of personal, interpersonal, and product and system building skills into the curriculum. These ideas can be applied to programmes in any branch of engineering, and almost every engineering sub-discipline is represented among the CDIO adopters around the world. Indeed there is increasing interest from other non-engineering disciplines in adopting many of the same principles.

One of the implicit requirements of a change in teaching and learning style is the need for learning spaces which are not 'lecture theatres'. Design-build-test exercises, team work and indeed many active learning techniques are best carried out in flat, open, flexible spaces. This does pose a resource problem in many institutions.

One example of the adoption of the CDIO approach is the School of Engineering at the University of Liverpool. The widespread adoption of active learning, set in the context provided by the CDIO standards, was greatly helped by the re-development of the School to include an Active Learning Lab (ALL) which enabled the whole yearly cohort of 250 students to undertake group activities simultaneously. The ALL was designed flexibly to enable a wide range of activities, as is necessary to support a diverse range of programmes, including aero, civil, mechanical, materials and general engineering. It contains large open spaces with specially designed team benches which can be moved around to configure the ALL for many different activities in the CDIO spectrum. It can thus be used for Conceiving (e.g. brainstorming in teams), Designing (via wireless laptops and rapid prototyping), Implementing (via adjacent workshop and testing facilities and using the ALL as an assembly area) and Operating (by clearing the floor to provide large open spaces for operation of devices or display of products).

The provision of a suitable physical space is clearly stimulating, but is not sufficient for embedding changes in learning and teaching styles. The project has, at the time of writing, been under development for seven years and fully running for only one. It will be at least another six years before a significant number of graduates have entered employment and real feedback on the success of the approach can be sought. Unsurprisingly, the single most difficult barrier to overcome has been the resistance of the academic staff to change. It is very easy to argue for the status quo ante when it takes 12 or 13 years to collect good evidence for the efficacy of a change. This is why leadership from the top is essential. Educational change of this magnitude cannot be undertaken on a fully 'evidence-based' basis; It has to be steered through by visionary leaders. (*See* 'How do we know we have improved anything?' in *Chapter 6*.)

What you might take away from this chapter:

- The realisation that most of the teaching in most institutions has changed little over the last four or five decades, apart from the relatively trivial introduction of on-line resources;
- The understanding that there are many alternatives to lecturing, most of which are being used by a minority of teachers spread across a wide range of universities. Many of these are more effective in flexible spaces which are unlike traditional lecture theatres;
- The recognition that, in a very small number of institutions, radical change has been tried but that engineering has not adopted Problem Based Learning as enthusiastically as has medical education.

Chapter 4: Curriculum content

Curriculum: A group of related courses, often in a special field of study: 'the engineering curriculum'. In UK terminology, the modules which make up a degree programme.

Syllabus: The subjects or topics studied for a particular module (USA: class): a document which lists these subjects and states how the module will be assessed.

A question: What does every engineer need to know?

a. Disciplinary 'technical' content

I cannot tell you anything about the important technical curriculum content in your programme. If you are working in an 'established' discipline such as mechanical or civil engineering you are probably aware of conventional topics which your community would expect to be covered. The programmes you offer will have programme-level learning outcomes, carefully constructed to reflect the expectations of your professional accrediting body, and aligned (in the UK) to the relevant QAA Benchmark statement [QAA, 2009]. If your discipline is younger, or you work in an interdisciplinary area, you may be more focused on content with topical excitement or immediate societal need, and you may feel less tied to conventional topics.

You may, in either case, have consulted potential employers of your graduates and you are probably aware of the curriculum, and possibly syllabi, offered by your competitor institutions, domestically or world-wide. However I am prepared to bet that, when you have consulted externally and among the staff who will be teaching the programme, you will have more suggested material than a student will readily be able to assimilate in the 3 or 4 years of the degree programme. Your problem is thus what to exclude, rather than what to include.

A question: What does each specific type of engineer (mechanical, electronic, chemical ...) need to know? You might ask yourself what you don't know in your own subject domain, and whether it makes you less of an engineer.

What follows has to be my opinion, rather than evidence-based advice. I would bear in mind three factors when designing the curriculum:

1. That most apparently urgent concerns of society tend to have a lifetime of about ten years. This is not to say that they are then ‘solved’ but that a different concern has dominated the headlines. For instance global warming is undoubtedly the preoccupation of the first decade of the 21st century, but this does not mean that population growth and feeding the world population do not remain hugely important issues. Attempts to align the whole of an engineering curriculum with current societal concerns are unlikely to be successful and are certain to be short-lived. However current concerns make a good basis for projects and design-build exercises.

   On the other hand the laws of macroscopic physics are most unlikely to change in our students’ working lifetimes (which may be in excess of 50 years), so they should form a large part of the learning which will provide the basis of their life-long development.

2. It is almost impossible to provide, within an engineering programme in a university, a comprehensive introduction to the business of business. Most advice from employers is not to try and do this. We need to help our students to work together in teams, and to develop some of the attributes which will make them readily employable, but these do not need to include how to read a balance sheet or how to negotiate with trade unions or how to sell the product. I find it hard to argue that non-engineering content – within the assessed curriculum – should exceed about 10% of the programme. Of course dynamic and entrepreneurial students might wish to engage in extra-curricular activities which will involve business issues, but so too they might wish to sing in a choir or train racing pigeons in their spare time.

3. If you agree with me that an engineering education should fit a graduate for a lifetime of work and/or interest in engineering, then it follows that she must understand the fundamentals at an early stage. It seems to me hugely preferable that the graduate has a secure grasp of a few principles than a sketchy passing knowledge of a broad range of topics. However the latter outcome is favoured by the widespread use of a 40% or 50% ‘pass-mark’ which reveals far more about what the student does not understand than what she does. I would use this perception to pare down to a minimum the <u>core</u> content of any module and any programme. Fundamental concepts must be understood, and therefore tested with an implicit pass mark of 95%. There are ways of doing this, while preserving the need to excite and extend the high-flying student with additional subject matter. For instance in an examination it would be possible to have a mandatory first question (worth say 40% of the marks) for which the pass mark was 95%, within a paper containing further questions to

test extended knowledge and understanding. The overall pass mark for the paper could still be maintained at 40% or 50%, but competence in the core material could not be avoided.

All three of these points imply that the engineering curriculum should contain relatively little material, but that this should be chosen to provide the most fundamental insights into the discipline. It is easy to say this, and I do realise that there remains a need to excite and motivate all the students in the short term, because the essence of my suggestion is that degree education (not training) is for the long term. The best way of doing this, it seems to me, is to make learning as active as possible, so that every student is engaged fully in learning.

b. Knowhow

> A comment: Almost all the students in your class have different prior experiences from you and from each other

Knowhow in the patent and intellectual property professions is used to signify private intellectual property, usually unpatented. It might include skills and experience with procedures and methodologies in a particular area. Knowhow is closely related to *tacit knowledge* – knowledge which an individual keeps in her head or her hands which is difficult to write down and codify but which may be hugely important to the success of a process. The possession of tacit knowledge may not even be recognised by its holder 'Oh – I've always done it that way'. Knowhow is often acquired by informal learning, rather than being taught.

I believe that knowhow is very important in engineering education. Consider some of the things which we rarely, if ever, teach:

How to use a micrometer, ratchet mechanisms, worm drive, the gear box, roughness, distortion (sound and vision), elegance (in mathematics, engineering or life), the value of a human life, characteristics of materials (metals vs polymers vs ceramics for a start – density, thermal conductivity, elemental composition), how a power station works, how to set up a Facebook site, how to upload a video to YouTube, how to use a spanner or a screwdriver, the carbon cycle, single-phase lighting circuit, how to use rotary and slider controls. All these are important aspects of an engineer's tacit armoury of skills. Should we be teaching more of them?

One action we could consider taking is to try to assess the knowledge (tacit as well as explicit) of our students as they join us. In the box is a possible list of items which might be given to students in the form of questions on their day of arrival at university. They would serve the twin purposes of pointing out to the students what sorts of things we expect them to know and simultaneously revealing to the academic staff what they actually do know! We would also like our students to be able to *reason*, using their knowledge, and this is discussed in the next section.

A list of things it would be nice if incoming engineering students knew or were able to do

Units (SI) and definitions Mass, length, time Joule, Coulomb, Density Orders of magnitude, multipliers such as k, M, G Plotting in Cartesian and polar coordinates Energy – conservation, kinetic, potential, internal, free Power/work Stress/pressure Momentum Mathematics Pi Binary arithmetic Equations of: Straight line, circle, parabola Area and circumference of circle Volume and surface area of sphere Exponentials/logarithms Solution of quadratic equation Differentiation Integration of simple function Probability Symmetry (mirror, rotational) Approximation General physics, chemistry, biology and engineering Levers Moments Meaning of the terms: Tension, compression, shear, buckling Centre of Gravity Newton's Laws of motion; velocity, acceleration Gravity; acceleration due to Ohm's Law	Orders of magnitude sizes – nucleus, atom, molecule, nanoparticle, CMOS, virus, cell, grain, hair, wire, aggregate particle, rebar, cylinder diameter or volume, wingspan, boat, longest bridge span, largest dam, diameter and circumference of earth How the following work: Light bulb 4-stroke internal combustion engine A lens CD player TV display Transistor Nuclear power station Gears and pulleys A worm drive Solenoid, microphone, loudspeaker Ball or roller bearing How to use: Word, Excel, Powerpoint Plot a graph A power drill A hacksaw A screwdriver, a hammer A digital voltmeter A spanner and torque wrench A protractor A micrometer An instruction manual Distinguish between: A screw and a bolt Mass and weight Size and volume Speed and velocity Series and parallel AC and DC Reflection and refraction Current and voltage

Concepts of charge, resistance,	Noun, adjective and verb
capacitance, electric field	Infer and imply
Magnetic fields, B, H	Thermoplastic and thermoset
States of matter; solid, liquid, gas,	Melting and sublimation
Atomic structure, nucleus and electrons	Heat and temperature
Bonding; Crystals, molecules	Rod and sheet
Characteristics of major groups of materials; metals, alloys, polymers, semiconductors, natural materials	Plan and section Jet and rocket RAM and ROM
The periodic table of elements	
	Welding, brazing and soldering
Balance a chemical reaction	Nuclear fission and fusion
	Sine and cosine
General knowledge	Wavelength and frequency
	Conduction, convection, radiation
Evolution	Lathe and mill
Cellular nature of living organisms	Cement and concrete
Photosynthesis and the carbon cycle	
Single-phase wiring circuits	

It is also useful to consider what makes someone an 'expert'. The Dreyfus brothers developed a five-stage model (see box) which goes some way to explain why it is often asserted that it takes 10,000 hours of practice to produce true expertise. We obviously cannot expect our fresh graduates to demonstrate such expertise after a degree programme which typically demands less than 5,000 hours of learning!

> Dreyfus and Dreyfus [1981] called the five stages of skill development Novice; Advanced Beginner; Competent; Proficient and Expert. You can read more detail if you wish but a key point is that at Novice level students have to stick rigidly to a set of rules, because they have not yet developed sufficient understanding of the overall topic. The measure of the Expert is that they have an intuitive grasp of what is possible and what is necessary, based on tacit knowledge (see above), and are not reliant at all on rules or guidelines.

c. Transferable skills

The ability to think critically is the paramount transferable skill for an engineer, and it is worth expanding a little on this, because it underpins everything we should be trying to encourage the student to learn. If you have the time, I recommend you to read the short booklet by Paul et al (2006). Don't be put off by its title 'The Thinker's Guide to Engineering Reasoning'. One of the most useful suggestions it contains is to set students to read an article, research paper or chapter of a book and extract from it the following key points:

- Its purpose (what was it written for?);
- The key question which it addresses;
- The main inferences or conclusions;
- The concepts, theories or ideas which we need to understand, in order to appreciate the paper;
- The main assumptions made by the author (whether stated or not);
- The implications of the author's reasoning (whether stated or not);
- The consequences if the author's conclusions are ignored; and
- The point of view taken by the author (if she was writing as an engineer, as a politician, as a mother, or what?).

The students could then prepare a critique and/or a summary of the document. Alternatively you could set up a 'journal club' to regularly review recent publications relevant to engineering.

The assessment of student reasoning skills is not entirely simple. A list of some resources to help can be found at http://www.ncsu.edu/per/TestInfo.html. One of the best-developed tools is a series of tests (and protocols for using them) devised by Anton Lawson which can be found at http://www.public.asu.edu/~anton1/LawsonAssessments.htm .

Lawson has constructed tests which can be given to incoming students to assess their ability to draw scientifically logical conclusions from simple data. The strength of his approach is that he not only asks questions but asks students why they think their answer is appropriate, thus revealing the nature of any misconceptions. Lawson's tests are customised for Physics, Chemistry, Science and Biology but the large majority of material in the Physics or Science tests would be applicable to engineering, albeit with a few words changed. I recommend them to you.

Another tool which is more oriented towards assessing attitudes to the learning of a quantitative discipline is CLASS (Colorado Learning Attitudes). CLASS was designed for students of physics but should be almost equally valid for engineering by simply replacing the word 'physics' with 'engineering'. [http://www.colorado.edu/sei/surveys/Faculty/CLASS-PHYS-faculty.html]

Of course there are many other transferable skills which we hope to inculcate in our students. These usually include critical reading (see above), writing, technical communication and oral presentation (with or without the ubiquitous Powerpoint). The conventional wisdom, at least in the UK, is that this is best done subtly via existing technical modules rather than separately by stand-alone modules on 'communication skills' or 'technical writing'. However this does imply that Programme Directors must check that transferable LOs are in fact delivered (but not too often) in the technical modules which comprise each degree programme. It is rather too easy to establish an 'oral presentation' element within six modules within a year, when one or two would serve the purpose and deliver the LOs.

d. Societal issues and attitudes

A comment: Many of the students in your class have different political, religious, cultural and ethical views, and different attitudes to engineering and to study, from you.

We can look at the various societal pressures on the engineering curriculum and on engineering programmes in several ways. I will divide these into three categories: Students' views on the society around them; Their views on the society they plan to enter, and; Their views on the nature of university study.

Society around us:

We cannot, and should not, ignore the reality that we live in a world containing war, famine, environmental damage, nuclear power, weapons of mass destruction, religions and climate change. Each of these may have an influence on the content of an engineering curriculum and the attitudes of the staff designing programmes and the students studying them. Depending on our society's ethical standpoint, and the expectations of its people, these influences may be very varied. We must also recognise the technological and social changes (I almost wrote 'advances' but thought better of it) relating to communication and travel – the internet, web 2.0, ubiquitous computing, intercontinental travel and the rapid integration of all of these. Finally, knowledge increases exponentially[1], forcing us to make choices about what is important and what is worth learning. At the level of individual undergraduate programmes we must, at least annually, consider what are the most timely and contemporary examples of engineering with which to illustrate our chosen content and make its societal context relevant to our students. At the same time we have to consider what new material to include and therefore what existing material to omit. Additionally we have to consider the teaching and learning methodologies which best encourage student learning. Usually very little of this gets done in the rushed 'annual programme review' which most universities insist on, although there should be more time for it in 5-yearly accreditation visits or major programme reviews.

[1] Actually, I don't think that knowledge does increase exponentially, because it has to be discovered by people, and the population is not rising exponentially (or at least soon will not). Perhaps it rises more than rectilinearly!

The society which graduates plan to enter:

Students – soon to be graduates – have widely different views on their future role in society, on the key issues in their home country – especially if it is in the less-developed world – and on their future career (or careers). This perspective will influence their 'take' on the programme you offer and their demands of you. Your possible response is not clear. The best advice is probably to use a wide range of example applications in your classes, although you probably believe that the fundamental engineering principles remain the same in any societal setting. You should be aware, however, that a western, developed world, approach to education is not universally accepted. During a project intended to make educational resources openly and freely available in the UK but therefore implicitly across the world, we were told that intellectuals in Pakistan were describing our 'open' approach – which was intended to be helpful – as educational imperialism. By making western-style support materials available to all we were in effect imposing our attitudes to engineering and to study itself on societies who could not afford their own alternative. I find this sad, but I simply report what we encountered.

Students' views on university study:

Now that the study of engineering at university is a mass-market activity we must expect to find a wide range of attitudes among our students. Among the issues which permit different attitudes to be taken are the following.

Competition among students or student teams both within the curriculum and outside it. Individual students may be comfortable with a different balance between competition as a stimulus to study and performance (our team's car is going to beat your team's car) and competitive pressures on resources or opportunities to be 'top'. You will meet, if you have not met them yet, students who resent having their marks (but perhaps not their performance) dragged down by weaker or slower students. I have had to discipline students who cut pages out of library books, both in order to take the material away for their own study and in order to deny other students access to it. I have even heard of (and I don't think the story is apocryphal) law students who would not agree to peer mark each others' work because a weaker student might learn something from their own efforts, in a field where the few top jobs with the best employing companies will go to those graduating with the best degrees. Thankfully I have never encountered this in engineering.

Most engineering students will find themselves studying among a mixture of home and overseas students. We might take the firm view that a UK university offers an experience designed to have a special UK flavour, but with many international links, so that its graduates are employable widely across the world. What then is the best balance of international students and home students? Is this different at School or programme level and within a student group or team? Is it different from the perspective of a 'home' student and an ‘international’ student? Is the balance which would deliver the optimum internationalised degree different from the balance any particular student might like? Are there students within your class who come from nations or ethnic groups which are currently at war, or occupied? These issues may directly affect your teaching.

How important is success to each student?

If you are teaching in a university which charges fees directly to every student (that is, not Scotland or Germany, for instance) then you will be increasingly concerned with student attitudes to value for money and the buying of degrees. Of course every student (and every funder of universities) should expect good value for money. Setting aside any governmental concerns, there are three key issues relating to students: Does the quest for funding and/or the extent of debt have a differential impact on different students? Do your students understand both the true cost of their education and what constitutes educational value for money? Are there students for whom a lower level of success than they expect can be a personal disaster? The answers are very likely to be Yes, No and Yes. We can do little except recognize the first issue, and prepare ourselves for social and moral pressures relating to the third. (There can be few engineering staff who have been teaching for more than five years who have not had tearful students assert that they ‘cannot’ go home with the – disappointing – award they have earned. I hope that there are none who have bowed to this pressure and relaxed their standards.)

The value for money issue is worth exploring further. It is very difficult to explain to students the actual cost of their education. (It is actually rather difficult to determine: The Royal Academy of Engineering’s report ‘Engineering Graduates for Industry’ (2010) tried but was only partially successful. Somewhere between £10k and £15k per student per year seems to be a reasonable estimate in the UK.) A student can focus on the perceived personal fee cost of £3250 per year (in England in 2009-2010) but every student I have spoken to on the issue cannot relate this to the cost of providing a lecturer-hour! The ‘value’ side of the value-for-money algorithm is also difficult to quantify. We hear that the possession of a degree is worth an increment of more than £100k on lifetime income but this is highly variable depending on the graduate’s choice of (and success in) career. How might the student put a value on being well educated, on having more life options, or on simply getting a job in economic circumstances when less fortunate students are unemployed? What value might one put on the pleasure and fun of mastering engineering? Nevertheless while I despair of putting a figure to the value for money (VFM) of an engineering degree, individual students will have considered their own position and will have assigned a value to their study/work/life balance. We, the teachers, can be sure that there will be a wide range of perceptions in our classes. Perhaps one of our duties is to explain (repeatedly) over the course of the student's programme the intrinsic value of an education in a quantitative discipline.

The most serious aspect of the perceived cost of a degree is in altering the attitudes of students to their rights, or more accurately, their perceived rights. Under a direct fee regime, education is no longer a free good. Some students will take the view that their payment gives them the right to a degree, others that it justifies their treating staff as hirelings for whom they have pre-paid. Most of my readers will be familiar with the symptoms: Emails along the lines 'Hi – send me the lecture notes again' or 'you were not in your office yesterday'. My most shocking anecdote is of a student who was challenged recently by a colleague and asked to stop talking during a lecture. When he refused my colleague asked him to leave, in order that the other students could benefit from the lecture. The student's reply was 'f*** off – I've paid for this!'. I am glad to report that my colleague held his ground and the student eventually left, but I am disappointed and saddened that the incident happened at all.

A strong anti-plagiarism culture has developed in academia over the last ten years, facilitated by the availability of software which detects (some) plagiarism. Most universities now ask students to attest that work which is submitted for assessment is their own, and that they understand that plagiarism is not permitted. However life is not this simple. Hidden behind this general British disgust at the theft of another's work or ideas are several other issues. A few of these are discussed in the following paragraph:

We actually want students to discover and use the work of others, and this is a skill which will be extremely useful in subsequent employment or research. We therefore tend to demand attribution – so that the student acknowledges the source of the information, idea or opinion. Even most 'open' resources (e.g. under Creative Commons licensing) demand attribution so that the author gets some credit. So far so good. But how much material should be harvested in this way? Here the behaviour we expect from a student is different from that which would be expected by an employer. An employer would be concerned at being protected from lawsuits relating to IPR, whereas academics are generally interested in the demonstration of understanding by the student. Understanding is poorly evidenced (although of course it may be there) if a student selects chunks of writing from another author, however clearly attributed. We also have to deal with the cultural perception (very deeply embedded in some countries) that it is a fine and honourable thing to repeat back to a master (you!) his own words. It has to be our duty, therefore, to explain to students that we are trying to assess their understanding, and that we can only do this if they demonstrate this by using their own words. This may mean that their explanation is less elegant than that from which they learnt, but it is their own. Even the assessment of knowledge is difficult in a written exam or assignment. A colleague, last year, suspected a student of cheating in an exam when he had merely memorised two whole pages of description and reproduced it word for word in the exam (although it was not an accurate answer to the question).This certainly demonstrated a wonderful memory, but told us nothing about the student's knowledge, let alone understanding. It was not cheating, but it was educationally useless.

The real answer to this is always to use oral examinations for the assessment of understanding, but I realise that in many circumstances this is impractical. We cannot just consider the curriculum from the student viewpoint. The society in which the university is embedded also brings its own values and priorities. Many of these mirror the students' concerns but in addition any university must respond to the concerns of its funders, which almost always include government and/or state as well as the students themselves. Considerations of value for money and affordability are thus inevitable, as are responses to national quality regimes (such as the QAA and professional engineering bodies in the UK). In addition, university academic staff will usually have deeply-held views on the importance of their own discipline, and they will hold strong opinions about standards of scholarship within it. In many universities they will also aspire to undertake research which requires particular graduate skills, and will therefore be enthusiastic to create a curriculum which provides particular elements even if they will only be needed by a small minority of graduates.

So society in its broadest sense (the people both within and beyond the university) inevitably plays a key role in influencing the engineering curriculum. Engineering curricula are usually only changed infrequently, because of the complexity of the task. However since staff changes are often more frequent than wholesale curriculum changes, opportunities can be found for incremental change as long as someone retains an overview of the whole programme. Perhaps Programme Directors should have quite a lengthy term of office, to ensure that this important overview is not lost. (I recognise that this might not be popular advice among Programme Directors!)

What you might take away from this chapter:

- Every student is different;
- There is much more to the student experience than the technical curriculum or even the taught curriculum. The problem is to devise and implement an appropriate set of experiences which either cover, or give the opportunity for the student to cover, the important non-technical issues;
- A good engineering curriculum cannot be static. It must change with society and with the students' prior experience, expectations and attitudes.

A question: If every lecturer had to publish all their teaching material openly, in advance, what would they want or need to do in a 'lecture' period?

Chapter 5: Teaching, learning and assessment

A question: Do all students learn in the same way that you did?

a. The lecture

Lectures are the staple of most existing engineering degree programmes. However, it has been known for many decades [Bligh, 1972, the book which first made me think about the effectiveness of various teaching methods] that the lecture is not particularly efficient as a way of developing either knowledge or understanding. It appears to be efficient in transmitting information, and particularly in appearing to the student to define the syllabus and thus the content to be examined. The lecture is thus popular with university administrations (who see it as an efficient mass transfer of knowledge), with students (who see it is a painless way of delineating what they need to memorise to pass the exam) and with staff, many of whom are still called 'lecturers' (who see it as the most-time efficient way of fulfilling their teaching duty). This is a slightly cynical view, which does not do justice to the good intentions of a number of thoughtful staff and students, but it contains sufficient truth to make it worth stating.

Sutherland and Badger (2004) reviewed the perceptions that lecturers themselves have about the lecture. They discovered that, in giving lectures to first-year students, 80% of lecturers were trying to transfer information and about half of them were also trying either:

- to demonstrate how something was done (e.g. a worked example); or
- to provide a framework within which the topic could be understood; or
- to motivate the students to study the topic or to improve their analytical thinking skills.

Sutherland and Badger were not able to determine whether any of these were successfully achieved!

A good question would be: If you started with a fresh sheet of paper, and adopted constructive alignment (*see Chapter 2)* to design your module, what material would you want to be delivered using lectures? I know that most of us do not start completely afresh because we inherit modules from previous staff and/or programmes, but let us assume a utopian situation. You will have started by distilling out, from your understanding and reading of the module topic, the key desirable learning outcomes (LOs). You will have checked that these are consistent with the programme LOs of any programme or programmes to which your module contributes. You will have checked the extent to which these outcomes are covered in other modules. You will have considered the best way for the students to master the LOs. You will be bearing in mind the time, spaces and resources available to you and the students. You conclude that some lectures would be useful, perhaps because:

- You have available an inspirational lecturer who stands a chance of firing the students with enthusiasm for the topic; [note that most of us are not very successful at this, even when we think we are – a lesson from the school of hard knocks!];
- You know of some wonderful demonstrations which clarify difficult aspects of the material and a one-to-many lecture is the easiest way of helping the students to get to grips with them, because you can add a commentary;
- You want the students to know who you are so that they will be able to approach you individually later;
- You want to bring the students together regularly so that they can learn to operate cooperatively;
- Your institution (or government) insists that you keep a register of student attendance.

You may conclude that some (or many) of the learning outcomes are best addressed by other means, which can include individual private study, but having decided to offer some lectures you will then want to make them as successful as possible, not in terms of student popularity, but in terms of delivering the LOs. You would then want to consider using one or more of the many techniques available for maximising the effectiveness of a lecture. Since almost all research indicates that a listener can only give proper attention to a speaker for about 15 minutes, you will probably start by breaking down your 'lecture' period into chunks of 10 to 15 minutes. In each of these periods you might deliver a mini-lecture but between these one-to-many sessions you will probably want to insert some 'active' elements.

You may also decide that, although you want to speak to the students for periods of 15 minutes at a time, it would be better not to do this in a conventional raked lecture theatre. Unfortunately the availability of flat or flexible learning and teaching spaces, and the limitations of the students' timetables, may inhibit your freedom of choice.

Active things to do in lectures:

- Feedback via clickers (personal response systems). Ask a question at least once every 15 minutes. If you don't have the technology (clickers) ask for a show of fingers ('raise 1 finger for answer 1' etc) or issue four coloured cards which can be raised. You can assess very quickly from the front of the class roughly how many of each response you have. You must of course be prepared to change what you say from this point on, to address the current state of understanding of the class;
- Exit questions – close the lecture with one or more questions to be done before the students leave the room;
- End of lecture summary – in the last 3 minutes of the class get the students to write down what they have learned during the class;
- Mud cards – issue post-it notes and ask the students to write down the one point they least understood and stick it on the door on the way out;
- Beauty cards – issue post-it notes and ask the students to write down the topic they feel they best understood and stick it on the door on the way out;
- Mini-tests – set a question for solo or group response at several points within the lecture. Use clickers if you have them;
- Recitations – set learning tasks for each member of a group, which he later has to explain to the remainder of the group. This could be done between two 15 minute 'lectured' sessions;
- Buzz groups or pauses for discussion – two minutes of reflective activity every ten or fifteen minutes keeps the students alert;
- Calculations – in a numerical subject, set a calculation every 15 minutes – to be completed alone or in groups;.
- Make jokes (careful, no sarcasm!);
- Do demonstrations or play videos – but not for long. These should be designed to illustrate something which cannot be otherwise experienced by the student, and to provide a break and a change, not to replace the lecture;
- Run a 'guided' lecture (see Bonwell and Eison, 1991, p 13) in which you define the objectives of the class, speak for no more than 25 minutes, without the students taking any notes, and then use the remainder of the time for the students to recall the subject matter and re-construct it for themselves;
- Ask questions, but then always pause for several seconds; most of us jump in too quickly to 'help' or answer the question ourselves.

> A question: What attitudes and approaches characterise a good engineer?

There are many techniques for adding activity to a basic lecture (see box for a list of ideas). Students can be asked to do something before, during and after a timetabled period, or all three. They can be asked to do this singly, or in spontaneous groups ('discuss with the students sitting next to you') or in predetermined groups (e.g. tutorial groups). Some lecturers insist that students always sit in these groups, so that they interact regularly with the same group of peers.

Some of the techniques which engineering lecturers have found to be helpful are listed in the box.

Note that although most of these techniques are only used by a minority of engineering lecturers, they are more common in school classrooms. One could argue that teaching at school level has been professionalised much sooner than university teaching.

There is no reason why you should not insist on the completion of some work before a class is started. This tends to be applied to tutorial sessions, but can equally be applied to lectures. Try setting a question at the end of each class (in person or on your VLE) and insisting that it be answered before the next class begins. Anyone failing to answer when called upon is asked to leave the class. Tough, but effective. Why should you waste your time on students who do not wish to learn? Surely, if you were a student in humanities you would not consider attending a class on Shakespeare's Hamlet without having <u>first</u> read the play.

Finally, you might – I regret to have to say – meet the issue of classroom control. This is likely to be more of a problem with large classes where you cannot easily look every student in the eye. It is also a natural consequence of active learning techniques that there will at times be a buzz of discussion in the class. Your problem then is to bring the class back to quiet attention at the chosen moment. It can be genuinely difficult to make yourself heard, particularly if, like me, you try to avoid using a microphone. One tip, which I have personally found to be very effective, is to use a referee's whistle to signal the end of a discussion period.

If you want to encourage deep learning (e.g. understanding of principles which can be applied elsewhere) you probably want to consider other teaching methods which are more effective for this purpose than the lecture, so read on:

A thought: One of the main reasons for the survival of the lecture is that you, like me, probably like giving a lecture. We became lecturers because we like theatre!

b. The tutorial

The word tutorial is used in different higher education contexts to indicate everything from one-to-one sessions to a lecture by another name. For our purposes let's define it as a timetabled activity with a group of students which is smaller than the full class, and during which the lecturer speaks for a significantly shorter time than the students. A tutorial could be face-to-face or could be conducted on-line or via a video link.

Some apparently universal aspects of the tutorial are:

- The learning which can be achieved is greatly enhanced if the students have done some relevant prior work. They should be ready to answer, as well as ask, questions about a specific topic whether it be something they have read, an experiment they have conducted or a calculation they have attempted (e.g. see 'recitations' below);
- It is difficult for most tutors to keep sufficiently quiet. The temptation to explain, resulting in a mini-lecture, is hard to resist for many (probably most) academics;
- One or more students will almost always keep rather quiet in a tutorial, while one or more are usually willing to speak a lot. (Two of us were actually banned from tutorials during one stage of my undergraduate programme because we dominated the discussion!).

Some comments which may not be universal but which are often reported include:

- Overseas students may prepare well, take liberal notes, but not be prepared to participate in discussion;
- On-line 'tutorials', especially asynchronous sessions involving bulletin boards or wikis, are better for encouraging 'quiet' students to contribute. The lack of face-to-face embarrassment, and the time to think and compose a response, are helpful for some students;
- Occasionally, students may be reluctant to introduce ideas because they see the quiet students as 'freeloaders' who are learning from others without contributing. There are even extreme cases where students wish to keep their knowledge to themselves for competitive advantage (e.g. see Sweeney et al, 2004).

Tutorials are surely to be encouraged in an environment where class sizes are increasing. They provide almost the best opportunity for students to learn both from each other and from their tutor (this is feedback – see below). End-of-lecture question sessions tend to be inhibited by constraints of time and space (the next lecturer is often waiting for the room!) so tutorials offer an excellent way of stimulating interactive learning. However lecturers would be well advised to insist on prior preparation of a defined piece of work by the students, and should consider supplementing the face-to-face sessions with an on-line forum in order to allow different types of student to contribute.

A useful variant of the tutorial is the *recitation*, which has the advantage – in these days of high student-staff ratios – that it can be carried out with group sizes of up to 25 or so. I will describe a version known as *ticking*.

All students are asked to prepare solutions to a set of problems. When they arrive at the class they are asked to tick, on a list, those problems for which they are prepared to present a solution to the class. The teacher selects a student at random (from those who have ticked that problem) to present the first problem, then another for the second and so on. If they demonstrate their ability to tackle the problem and lead the class through it, then their tick remains. Otherwise it is deleted. Over a semester all students should have presented one or more problems, and collected ticks for several more. The assessment of the class is based on the number of ticks collected, not on the actual presentations. If you felt tough enough it could be a condition of entry to the exam that a student had collected a certain number of ticks! However you organise it, the underlying idea is that you encourage all students to attempt most of the problems, while each problem is only presented once. This is both motivational and time-effective. It also provides immediate feedback (*see section m below*).

c. Problem-Based Learning

Problem-based learning (PBL), at its most straightforward, involves posing a question (usually but not always open-ended) to a group of students who are provided with resources and a facilitator, but no lectures. It is widely used in medical education. In engineering the problem might be in the context of design – 'devise a system to … the lowest cost system meeting the specification wins.'; or 'advise a car manufacturer how they can reduce the weight of their car door without losing impact resistance and without increasing cost'. Well-designed problems will require the students to engage in both qualitative and quantitative investigations which are new to them. PBL can also be used in a more academic engineering science context and in other professional engineering contexts such as management.

The justification for using PBL springs from the work of two extremely well-established intellectuals: Socrates espoused the dialectic method – leading and guiding students to discover for themselves: Jean Piaget – rather more recently in the first half of the twentieth century – discovered that children learn by doing, and that understanding is largely unaffected by direct instruction. He was working with younger learners than we are, but many people believe that there is still a large measure of truth in this axiom at the undergraduate level.

A key element of most PBL is that the students work in groups or teams. This implies that, before or during their first PBL exercise, they will need some training in the basics of team work (*see box in Chapter 3, p 29*). PBL can be used within a module, as the basis for a whole module, or as the context for a complete programme (*see example below*).

PBL can also refer to Project-based learning, which shares many characteristics with problem-based learning (see next section), particularly the lack of lectures and the reliance on the students' own efforts to discover and understand. Enquiry-based Learning (EBL) is also very similar and there is a Centre for Excellence in EBL at Manchester which offers many resources on its web site [http://www.campus.manchester.ac.uk/ceebl/ebl/].

For a more detailed exposition of PBL I recommend that you read Overton [2005]. For some examples of project topics see the box on *page 30.*

There is also an excellent report on the SHEER project which examined the attitudes of academic staff to PBL in 2008 [MacAndrew et al, 2008]. This report contains a very good discussion of the nature of PBL, its strengths, weaknesses and practicalities. It includes such insights as (my comments in *italics*):

- 'A problem that is too simple or too complex will be counterproductive'; (*see Vygotsky's zone of proximal development in Chapter* 2);
- '[Lecturers] defined problem based learning in terms of active learning rather than passive absorption of knowledge. They put great emphasis on the technique as a means of inspiring thinking skills in their students';
- Real-world problems are often fairly straightforward and do not necessarily require the qualities of a graduate' (*you could debate that one for a long time!*);
- 'All [lecturers] equated problem based learning with students working together in small groups in order to promote engagement by students';
- '[Several lecturers] argued that part of the pursuit of excellence in teaching is that everyone ought to be using problem-based learning all the time. They went further in suggesting that it was impossible to teach properly without some element of problem-based learning in your teaching methods';
- 'You have a lack of control over what they learn or the resources they use. Also they tend to remember bizarre things after class – they don't always learn the thing you wanted them to';

- 'There was agreement that well conducted problem-based sessions had a positive effect on students' understanding' (*NB: not learning, but understanding)*;
- 'When new lecturers start to teach they try to put in everything and this is not how you should do PBL';
- 'Some cultures engender obedience and strongly discourage challenge to authority or any form of questioning. Students from these backgrounds are likely to be bewildered by problem-based learning. These students must be helped to feel empowered in order to benefit from a problem-based approach' *(this is a very important point, but a difficult one to deal with)*;
- 'The loudest voice isn't always the most accurate, however authoritative it might seem. Also, if they then share incorrect information it is a real problem';
- 'The physical environment dictates what you can and cannot do' *(up to a point, Lord Copper)*.

Remember – these are not my points but those of practising lecturers.

So, if you decide to incorporate PBL, or indeed any teaching innovation, into one or more of your modules, how might you set about it? My check-list would be:

- Construct the desired learning outcomes from your module. Remember that your LOs could include being effective while working in a team, and delivering outputs on time;
- Check these against the LOs of the programme your module(s) contribute to. Revise your LOs if any particular outcome appears several times in other modules. (Twice is OK, but five times is probably not.);
- Consider the best methods of assessing these LOs. Again check that you are not overloading the students with one particular form of assessment (e.g. written reports or oral presentations);
- Devise, in general terms, a problem which is open ended, has qualitative and quantitative aspects, builds on understanding the students should have acquired at this stage, requires some (but not a huge amount of) new knowledge and new ideas, and leads to assessable outcomes; [This is probably your hardest task.]
- Negotiate with your Programme Director, L&T Chairman or Head of School for the resources you will need to deliver the module. You cannot do this earlier because you need to develop an outline of your problem first. However there is no point in going further if you will not have the resources to deliver it;
- Clear the administrative and quality procedures within your institution which apply to new or revised modules;
- Enlist help with the detailed planning stage. You might consider employing (paid or as volunteers) postgraduates, undergraduates who

have recently completed a similar module and/or staff from your university's educational development unit;

- Plan your approach to the many practical issues, which will include: Size of team; selecting the composition of each team; entering teams on your local VLE; location for project work and team meetings; training in team work (if not done already in earlier modules); number and timing of deliverables; whether to include a peer assessment element; who is to do the marking; mechanisms and timing of feedback to the teams;
- Prepare (preferably using your helpers) briefing notes; deliverable pro-formas; data (is each team to use different data or work on a slightly different problem?); assessment pro-formas;
- Brief and train the tutors, teaching assistants (TAs) and any others involved in helping with the running of the module;
- Run the module for the first time;
- Get student feedback (it is amazing how many questionnaires will be returned if you offer just a single mark for completion!) and consider the range of student marks;
- Revise the module and, if necessary, its assessment procedures;
- Report your findings and analysis to a conference on engineering education.

d. Project-Based Learning

Project-based learning is often confused (or conflated) with problem-based learning and both usually carry the acronym PBL, although Graham (2010), in a recent very comprehensive report, has coined the abbreviation PjBL.

A definition of PjBL given by Prince and Felder (2006) is:

> 'Project-based learning begins with an assignment to carry out one or more tasks that lead to the production of a final product — a design, a model, a device or a computer simulation. The culmination of the project is normally a written and/or oral report summarizing the procedure used to produce the product and presenting the outcome.'

Two institutions which have devoted a lot of time to PjBL (both in developing it, and in offering it in their curricula) are Aalborg University in Denmark (http://en.aau.dk) and Franklin W Olin College of Engineering in Massachusetts (www.olin.edu). You can even study for a Masters in PBL (with PjBL) at Aalborg if you want to take it very seriously! However there are many more modest examples of project-based activities at many universities in the UK and elsewhere. Indeed Graham comments that the majority of PjBL in the UK is delivered through isolated modules by a small number of champions, posing the problem that such developments are rarely sustained beyond the tenure of the champion. A further, more surprising, comment is that the majority of PjBL experiences do not involve a hands-on element. It is not clear whether this dominance of paper-based or web-based exercises results from constraints imposed by lack of finance and suitable spaces, or whether teaching staff want to run them this way.

A key issue for the delivery of effective PjBL (or PBL) is the training of facilitators. Graham (2010) comments on this, as does anyone who has tried it. Effective learning via projects or problems requires significant human resources. The School of Computer Science at Manchester may be an extreme example, but Graham reports that they deploy, for a PBL module with a cohort of 250 students in teams of 6, two academic co-ordinators, 40 tutors and 12 graduate student 'demonstrators', together with some external guest lecturers. Clearly the tutors are only occasionally involved, but all these people need some training to ensure that they facilitate, rather than 'demonstrating' or 'lecturing'.

Colleagues commonly ask how we know that techniques such as PjBL are effective. Here at least there is some evidence, in a meta-analysis by Strobel and van Barneveld (2009) that PjBL enhances long term retention, skill development and satisfaction (of both students and staff!). Satisfaction is, if you like, a bonus – but an improvement in long term retention is very much to be welcomed. However I cannot find any thorough analysis or evaluation of whole engineering programmes delivered partly or largely by PjBL or PBL. Those evaluations which have been performed can be found on the PBLE (Project Based Learning in Engineering) web site (www.pble.ac.uk) or on the site of the Engineering Subject Centre (www.engsc.ac.uk).

A good resource to support PjBL is the Handbook assembled by Hadgraft (2009) for the University of Melbourne but openly available on the web.

For tips on how to incorporate PjBL into your teaching, look at the check-list of actions given at the end of the previous section on PBL. I will close this paragraph with a last quotation from Graham (2010). 'The single most important element for the adoption of sustainable and successful PjBL activities is the creation of a culture/environment of support, promotion and reward for excellence and innovation in engineering education'. I agree.

Graham (2010) identified seven highly-regarded and transferable types of PjBL projects. These are:

1. Icebreakers (where team building is more important than the product);
2. Partnerships with local companies;
3. Product design;
4. Video production;
5. Robot competitions;
6. Artefact analysis and improvement (reverse engineering);
7. Crime scene analysis.

I would add another:

8. Social service projects, which might be based around a specific person with a problem, rather than a specific device (e.g. ten projects on the theme 'make Tracey's life better')

Some specific project and problem topics which have been used in the past include:

- Design, make and test a cardboard bridge to span a specified gap;
- Design, build and fly an aircraft to carry a specified load, or fly a specified course, or stay up for a specified time;
- Build a robot to make and deliver a mug of coffee to you from the other side of a barrier;
- Use Lego Mindstorms (or similar kits) to control a robot to ….;
- Build a tenth-scale building, dam or bridge (e.g. at the Constructionarium);
- Design, build and predict the height attained by a water-powered rocket;
- Dismantle a familiar object (e.g. power drill) and redesign to improve some aspect of performance (Mechanical dissection);
- Re-design the control surfaces of an aircraft to improve its flight handling qualities (to be tested in a flight simulator);
- Make a video to demonstrate …;
- Design and make an interactive science/engineering demonstration for school pupils;
- Design and develop an engineering 'app' for the iPhone or iPad;
- Draw specified conclusions from a crime scene;
- Develop an eco-house;
- Design, build and race a Formula Student car;
- Design and build a low-cost low-tech pump for drawing water from a well in Africa;
- Improve the efficiency of a turbine;
- Recommend to the manufacturer an improved material for a car door (or similar component);
- Design and make a vertical wind turbine;
- Produce an alarm to warn when the bath is full;
- Design a new ice cream;
- Improve ambulance trolleys to reduce the impact on the patient;
- Make a two-wheeled balancing vehicle;
- Design and build an instrumented small-scale rollercoaster to enable young pupils to conduct experiments on kinetic and potential energy;
- Design a robot to detect and locate the carotid artery in the neck;
- Ask the external community for projects: assistive technologies; developing world projects (e.g. via Engineers without Borders); human-centred projects
- Devise and produce a game to illustrate an engineering principle.

It is worth considering one example of a PjBL project in more detail in order to draw out some of the possibilities. I will describe the 'Foam Skyscraper' project which was developed under NASA funding [CDIO in Aerospace Engineering Education; NASA E.2 Innovation in Aeronautics Instruction (IAII-08)] in 2008-09 and for which detailed instructions and guidance notes are available. This project can be carried out over a period of a few hours – an afternoon or a whole day. The challenge is simply to build the highest tower out of rigid foam and pencils. The recommended constraints are that the completed tower must support a 0.5l bottle of water and must be stable against being tilted about any arbitrary axis by a specified angle (e.g. 1 in 10 or 6 degrees). The details are;

- Foam is available in one thickness (e.g. 2 inches or 50mm) and several slab sizes;
- Fasteners (pencils sharpened at one end) may not be broken or cut;
- Each team has a fixed budget, and must pay for:
    - The land on which the skyscraper is to be built (per unit area)
    - The foam (per slab);
    - Cutting the foam (per cut);
    - Fasteners (per pencil);
- Each team must in sequence:
    - Establish and keep a log
    - Produce a plan and a schedule of actions;
    - Get their plans signed off by a 'building inspector'
    - Build the tower according to their plans
    - Subject their tower to testing (i.e. tilting)
- Materials are limited, so there is a finite number of each foam slab and a finite number of pencils.

This project thus requires teamwork, planning, design, time constraints and finance, plus a very small amount of calculation (essentially just a centre of gravity estimate). Potential variants could involve further constraints such as rule changes or material cost changes during the project. You may find (and therefore need to think about) possible team behaviours such as cornering the market in a material, arguing about the land area required, or introducing materials other than the two provided. These can lead to very interesting debates about ethics and the real world in which construction projects are carried out. Because it has low technical requirements the foam tower project is very suitable as an 'icebreaker' at the beginning of an undergraduate programme, or as a light-hearted activity for an awayday (for staff or students).

e. Student Centred Learning

> A comment: Some of the students in your class are probably quicker and smarter than you; (I always hope so!)

It is almost a cliché that we would like students to be confident and self-motivated, to 'take control of their own learning' or 'own their own learning' and to regard academics as one of the most valuable among the many learning resources available to them. This ideal is what we usually mean when we refer to student-centred learning. It is also called 'Learner autonomy' which is the basis of a Centre for Excellence in Teaching and Learning at Sheffield Hallam University [2010].

Every debate I have ever participated in concerning the desirable attributes of a graduate concludes with 'confidence'. This is confidence in what he does know, confidence in what he doesn't, confidence to find out, confidence to ask questions and, particularly in engineering, the confidence to fail and to learn from those failures. The question for us is how might we encourage and develop this confidence in our students, and this is where the second aspect of student-centred learning comes in. As well as encouraging the student to take charge of his own learning we have to put the student at the centre of our teaching. I don't want to sound too pious, but we should consider every aspect of our teaching from the perspective of the student. Try to suppress 'it would be a chore to mark this lengthy piece of work' and elevate the thought 'the student would learn so much more if I gave detailed comments on this assignment which has clearly taken him many hours to prepare'. I understand that the time available is unlikely to be sufficient to do the best job you know how to do, but we have to challenge ourselves at all times (and bear in mind that even in a research-intensive university it is likely that 50% or so of your salary comes from teaching funds!)

In the words of Ivan Moore, the former director of the Hallam Centre for Promoting Learner Autonomy [http://extra.shu.ac.uk/cetl/cpla/cplahome.html], autonomous learners:

- are well motivated to learn;
- can identify:
    - their learning goals (what they need to learn)
    - their learning processes (how they will learn it)
    - how they will evaluate and use their learning
- have well-founded conceptions of learning;
- have a range of learning approaches and skills;
- can organize their learning;
- have good information processing skills.

We can promote learner autonomy in many ways, but underpinning these has to be the expectation by academics that students will take control of their own educational destinies. If this context is clear, then many of the active learning techniques described in this chapter will help to motivate students to learn and will encourage them to take ownership. These techniques include PBL, PjBL, WBL and cooperative learning. The literature makes clear, however, that there is no magic bullet; we are trying to inculcate an *attitude* to learning, to engineering and to continued and continuous development of the student and then the graduate. Teaching staff must expect these attitudes to develop throughout the student's programme, starting from the first day of year 1.

f. Active Learning

Whole books have been written about active learning, as an approach to education at all levels. As with many topics (so my teacher friends tell me), higher education has woken up to it later than schools. Unfortunately the very scope of the approach means that there are a legion of examples and explanations. I have found that, over the past ten years, I have been asked to explain what I mean by this phrase more than any other. The best short definition I have found dates back to 1991 in a book entitled 'Active Learning: Creating Excitement in the Classroom' [Bonwell and Eison, 1991] and it simply states: 'Active Learning involves students in doing things and thinking about the things they are doing'.

Active Learning can take place in the lecture room, in the laboratory, during design or project work, and is hard to avoid during team or group work. It can take place while the student has a screwdriver in his hand, or a pencil, or a keyboard or a phone. It is less likely to take place when the student's hand is empty, but is still possible if the student is actively questioning or debating.

Most of the other sections of this chapter implicitly involve active learning, and I have indicated above a number of ways in which a lecture can be made more active, so it is not really necessary to further develop the theme of active learning here: most of this book is based on the principles of active learning (but reading it will only be active if you have a pencil in your hand – yes, you can mark the pages!).

Michael Prince (2004) has written an excellent review of the pros and cons of active learning. He critiques the literature on Active Learning, Collaborative Learning, Co-operative Learning and Problem-Based Learning and he is careful not to over-sell the potential benefits of any of them. Three of his key conclusions are:

- Students will remember more content if activities are introduced to the lecture;
- The best available evidence suggests that faculty should structure their courses to promote collaborative and cooperative environments;
- Faculty adopting PBL are unlikely to see improvements in student test scores, but are likely to positively influence student attitudes and study habits. Studies also suggest that students will retain information longer and perhaps develop enhanced critical thinking and problem-solving skills.

Some good evidence:

Richard Hake studied the mechanics understanding of more than 6500 students (using a Force Concept Inventory). Using before and after tests he measured the gain in understanding following both conventional teaching (‘chalk and talk’) and ‘interactive engagement‘. He found that the learning gain after interactive engagement (<g>=0.48) was about double that for conventional methods (<g>=0.23)!

For those who want to know more, Hake defined ‘gain’ in terms of the average marks of the class before ‘i’ and after ‘f’ being taught. He defined the average normalized gain <g> for a course as the ratio of the actual average gain <G> to the maximum possible average gain, i.e., $<g> = \%<G> / \%<G>_{max} = (\%<Sf> - \%<Si>) /(100 - \%<Si>)$, where <Sf> and <Si> are the final (post) and initial (pre) class averages. For example if the average performance of the students ‘before’ teaching was 45% then the maximum possible gain $<G>_{max}$ is 55 percentage points. If the average ‘after’ teaching is 60% then the gain <g> is (60-45)/55 = 0.27.
Hake’s paper can be found at: http://physics.indiana.edu/~sdi/ajpv3i.pdf

g. Co-operative Learning

Co-operative learning is a phrase which is widely used in school pedagogy, but less frequently in higher education circles. It refers to the benefits to students of learning in collaboration with other students. I do not propose to write about it specifically, because the essential points have been covered in the sections on group and team work, on problem and project-based learning and on active learning (qqv). However this is a good place to introduce a co-operative technique known as the *jigsaw* classroom (or *pair-share*). After teaching a particular topic, but while the class is still together, you pose a question to the whole class and give all students a few minutes to consider their own answer (e.g. from their lecture notes). Students then form pairs and present their solutions to each other. They then formulate a joint answer which combines the best features of their individual solutions. You then call on random pairs to present their agreed solution to the class. As with many active and collaborative techniques, this provides immediate feedback to all the students present. (*See section m below*)

h. Technology Enhanced Learning, including E-learning

I tried to define e-learning in *Chapter 3* and recommended that you look at the book by Diana Laurillard (2002). You should also look on the web site of JISC (the Joint Information Services Committee of HEFCE, www.jisc.ac.uk) for reports of the many IT projects they have sponsored over the last few decades. It might help you in thinking about e-learning to distinguish between e-learning (students using a computer or mobile device to access learning materials) and e-delivery (the teacher using technology to help with the delivery of teaching). I emphasised earlier that good e-learning should offer activities which cannot be provided by a handout, a book or a whiteboard. I will now try to suggest some specific technologies which you might consider using.

Personal response systems (clickers) allow students to respond instantly but anonymously to your questions during classes. Most systems require dedicated keypads (one per student) and a small receiver which plugs into your computer. The two great advantages of clickers are that you can find out during a class whether the students are having problems, and that you simultaneously collect a record of individual and aggregated responses which you can not only use in real time but also can analyse at leisure as you try to improve your class next year. The Wikipedia article 'Audience Response' provides some good background.

Although clickers are sometimes light-heartedly dismissed as 'Who Wants to be a Millionaire? buttons' they have several really useful applications. At the simplest level, if used sparingly (perhaps 3 or 4 times in an hour session) they can break up the monotony and force student interaction at just the optimal time – the end of their 15 minute concentration span. Alternatively they can be used to conduct a formative test during a class. They are some advantages to allowing students to anonymously assess their own progress; A student who got the question right but sees that there is a significant minority of students who didn't may be more tolerant of the lecturer's need to repeat material. In the opposite direction a student who sees that he is among a small minority of people who didn't 'get it' might be spurred on to try again knowing that it is possible to understand it. The key point is the anonymity of the responses, giving the student the confidence to respond truthfully.

Taken more seriously, you can use clickers as the basic tool for what is usually called peer instruction[2] . Eric Mazur (a physicist) has championed the use of concept questions with clickers. A concept question is one which requires an understanding of the underlying concepts, but usually require little in the way of factual knowledge. A well-known example, from the popular Force Concept Inventory (Hestenes, 1992), might be: If a heavy truck collides head-on with a car are the forces on each vehicle at the moment of impact a) greater on the car; b) the same, or; c) greater on the truck? This requires no calculation to answer, merely an understanding of Newton's third law and the ability to distinguish between force and momentum.

There are not yet major compilations of concept questions in Engineering, but collecting them would be very worthwhile and I believe that the NSF has just funded such a project, ciHUB, in the USA [http://cihub.org/]. For some initial

[2] Notice the unfortunate use of the word 'instruction' again

details see http://www.foundationcoalition.org/home/keycomponents/ concept/ index.html.

Mazur suggests that every class period (which might previously have been called a lecture) should be preceded by the setting of a student study task (e.g. reading about the topic to gather some knowledge). The class then proceeds in the following way:

- The lecturer asks a concept question, asking the students to think about it and answer it on their own;
- The answers are collected via clickers;
- If > 70% of the answers are correct, a further (more difficult) question is asked;
- If < 30% of the answers are correct, a further (easier) question is asked;
- If >30% and <70% of answers are correct, each student is asked to turn to her neighbour, who is highly likely to have answered differently, and discuss their reasons for answering, and arrive at an agreed answer;
- The answers are again collected using the clickers;
- The fraction of correct answers is now usually much higher, and an explanation might be given to the whole class;
- A further, more difficult, question is posed and the class continues.

The key element in this procedure involves students explaining to each other why one answer is more appropriate. This involves a number of good features. It attempts to resolve misconceptions by getting a peer to explain the issues – the peer student is in the best possible position to appreciate the difficulty. The students also gain experience in explaining, thereby learning rapidly as they have to ‘teach’ someone else. This is the ‘peer instruction’ activity. Usually the student with the correct understanding will prevail, but if she does not, the subsequent explanation by the lecturer should clarify the situation.

An essential aspect of this peer instruction process is the use of good concept questions. Writing these is not trivial, and the engineering education community needs to work together to develop an extensive database of questions.

There are a few issues to consider before starting to use clickers:

- If you choose to use clickers during a class, then you must be prepared to adjust your subsequent teaching in the light of the responses you get. This means you may not get through everything you had planned, but you will be more certain that the students understand the material which was treated;

- The capital cost is significant, but it is usually tied to the handset so could be charged to the student;
- The set-up time for the lecturer is very small (a minute or so), once the software has been installed on your laptop at the start of the year;
- The time overhead in using clickers is much reduced if the handsets are either owned by each student or permanently stored in the class room. I am aware of institutions which issue a numbered handset to each student at the start of the year, and other institutions which install boxes of handsets near the door of the lecture room and ask the students always to use the same number handset. In both cases you can use the fact that each handset is associated with a specific student to take a register of attendance, to monitor the responses (and hence understanding) of specific students and also to select random students to answer questions or to justify their answer;
- The type of question which can be answered (and thus asked) is nowadays very wide. The latest handsets and software allow multiple choice responses (one or many answers), correction of answers after a re-think, numerical answers and even text entry;
- There have been some experiments (in the USA) with the use of mobile phones, or even on-line web sites as personal response systems. This works, but carries some installation overheads and the business model for paying for the service and charging the students for a phone which might not be their idea of the most desirable phone makes for problems. I am not aware of any such installation in the UK yet. The use of mobile phones to send answers by SMS (texting) seems to be taking over, because it does not require a specific phone (see below);
- Finally – almost all students like clickers. I have been a user for several years with first and second-year and the most frequent question from students in later years of their programme is 'why don't we use clickers any more?'

There are plenty of low-tech alternatives to clickers. You can issue coloured cards, or ask student to hold the appropriate number of fingers in the air or against their chest (it is quite easy to scan a large class and see the range of responses) but the huge disadvantage of these methods is that the student's response is not anonymous – they can look around to see what their peers are voting, and indeed they may be inhibited from making the response they believe to be correct because of peer pressure.

Texting

We can now assume that every student in our class has a mobile phone capable of sending and receiving SMS (texting). This opens up possibilities for using this familiar technology (at least, familiar to the students, many of whom are probably using it as you speak in a class). Texting has some of the advantages of clickers – principally anonymity of the sender (to his neighbours) but individually attributable by you. It permits bulk sending of, for examples, questions to a whole class or year group. Your university computing or telephone services probably offer a bulk texting facility to class lists of students. It also permits great flexibility of response, but as yet there are almost no systems which can organise and collate the student responses. Texting, because of its familiarity and ubiquity, can be decoupled from class times so in principle allows the student to consider questions after class and then respond. However some observers have found that because of the implicit immediacy of texting, students either respond immediately or not at all. The MELAS project at the University of Wolverhampton explored many of these issues and its final report can be read at http://www.jisc.ac.uk /media/documents/programmes/elearninginnovation/melasfinalreport.pdf

Podcasts

The technology to 'podcast' an audio or video file is now well established. The file can then be reviewed on a mobile device such as an MP3 player or smart phone. It is not dissimilar to mounting a recording of your lecture on your institution's VLE. Many lecturers are doing this, so that their students can review the lectured material if they were absent or ill. An equally useful technique, adopted by many students who are listening to the lecture in their second or third language, is to review the lecture more slowly, with frequent pauses to assimilate (or replay) words which were not understood first time. This seems to me a very good idea, although I have colleagues who comment that some students will use absolutely everything you make available, so a few students who don't really need a further review of the material may spend time on it, simply because it was provided. To which I reply that if the student properly owns his own learning, then he should not choose to repeat exercises after he has achieved understanding.

A more interesting way to use the technology of podcasting is to broadcast timely updates on your module or programme. John Fothergill at the University of Leicester, for instance, prepares a five minute audio podcast every two weeks during his module. On it he records items he has heard or read over the intervening fortnight which provide contextual background to the module. There can be few topics in Engineering which are not amenable to this sort of treatment, with some sort of application in the news. Since all of us, I am sure, read one or more technical journals as well as the general news this is not a demanding task. The resultant podcast both adds relevance and context to the students' learning and also gives the (correct) impression that the world of engineering is not static and is relevant to society. Finally, a number of lecturers report that students do listen to feedback in the form of a podcast. This is an easy way of giving timely user-friendly feedback to the whole class.

Wikis and blogs

Many lecturers, although few as yet in engineering, establish blog or wiki sites for their students. This facility is usually available within your university's VLE, so does not involve using an external site. The strength of either of these technologies is that they enable students and staff to help each other, to ask questions, and to learn asynchronously beyond the timetabled class periods. The weakness is that engineering does not appear at first sight to be a subject where discussion or opinion plays a large role. However I remain hopeful that wider use of these shared facilities will encourage the transfer of understanding among students and the spread of positive attitudes about the study of engineering. The big advantage of an academically-initiated blog or wiki is that it is not immediately considered as a purely social site, as might be the case for Facebook, for instance.

Facebook

As I write, Facebook is the dominant social networking site – although it might not be by the time you read this. However I wager that social networking is still an important feature of student life. The question for us is, to what extent do we attempt to use such sites for academic purposes? My answer is that we should not, for a number of reasons. These include the feeling that we should encourage our students to take engineering more seriously than is implied by a purely social setting, together with the desire not to be perceived as snooping on student behaviour which is, I would argue, none of our business. However, while I don't think we should consciously use Facebook, I welcome student behaviour which makes use of such technology to arrange meeting of groups and teams. I just don't think we would succeed in demanding such behaviour.

Second Life

On-line environments such as Second Life have a superficial appeal for universities, but have not proved successful – certainly in engineering. It is relatively straightforward to create an academic space in Second Life, and to populate it with lectures and study support material but I do not believe that this represents good value for our effort. It is time-consuming, if not particularly difficult, to establish a useful presence and I find myself unpersuaded that the resultant environment offers more to the student than his institution's own VLE. Effort spent in creating a credible second world for your programme or module will be considerable and the resultant environment, even if initially of high quality, is unlikely to survive more than a few years. Second Life is already a bit passé and is perceived as a leisure environment rather than a study environment, so I would not bother with it.

YouTube, Scribd, Slideshare, Flickr …

There is a plethora of file-sharing sites. Currently YouTube clearly specialises in video clips, Flickr in images, Slideshare in presentations and Scribd in text files, although the borderlines are becoming blurred. Other sites will undoubtedly emerge.

The academic argument about using these sites is qualitatively different from that for Facebook or Second Life. These are not sites occupied by students, but sites searched by students and staff in search of useful material. You have probably already included a clip from YouTube in a lecture. Recent experience with a project on Open Educational Resources (core.materials.ac.uk) indicates that resources designed to be used for teaching (micrographs, video clips, animations, lecture notes) are discovered more frequently on these 'Web 2.0' sites that on sites designed to provide academic support. So if you want your material to be used by students and teachers around the world (and if it's good, why wouldn't you?) consider uploading it to a Web 2.0 site. It will be found more rapidly by a search engine than if it is buried in your VLE.

On-line tests

My final example of technology to enhance learning is the on-line test. There are two (perhaps three) huge advantages of on-line testing: the marking is instantaneous; questions can be re-used, and; (if you have the technology) formative feedback can be offered immediately. Most universities now have access to a VLE which incorporates an on-line test capability, and there are also stand-alone commercial products (e.g. Question Mark) and publishers who offer on-line tests with feedback (at a price, e.g. Pearson's Mastering Engineering). There are also question banks available in some subject areas, often available via the UK Subject Centres.

Some of the issues to bear in mind when using on-line assessment are:

- Many question types are now available, so the days of over-simple 'choose one correct answer from four' are long gone. You can use drag-and-drop, multiple correct answers, clicking on an active image, numerical answers or even textual answers (but beware the time it might take to mark these);
- On-line tests can be formative or summative – you can offer them for practice, or for marks;
- Tests can be timed – both in duration and in the window during which they are available;
- You can usually select whether the student can have a single attempt or multiple attempts. Bear in mind that some students will take a perfectionist approach and strive to get everything completely right.

This may not be the most effective or appropriate use of their time, so you might not want to permit unlimited attempts;

- Remember that in all cases except when you are patrolling a test in pseudo-exam-room situations the students can consult other resources (including their friends) while they are taking the test. You might consider allocating each student a random sub-set of questions from a larger bank, and setting questions which are not amenable to looked-up answers.
- You can add a question or two to any test to get feedback from the students. This is likely to attract a better response than an end-of-module questionnaire and in addition is less onerous and more timely.

I will close this section with a word of warning. Consider carefully the cost-effectiveness of engaging with any specific technology. Whatever the technology, we can be fairly certain about two things: It will be fun, but it will take a significant amount of your time to master it (and mastery is needed or you will simply lose credibility with your students when things go wrong or are perceived to be clunky or passé). And it will not be around in its current form for more than 5 years. In the week I am writing this, the iPad has been launched and Bebo has been withdrawn. You are unlikely to have used the social networking site Bebo since you were 12 (if at all) but the point is that a technology used by tens of millions can (and regularly does) disappear in an instant. These are not reasons for you to ignore the latest technology, but they are reasons why you should focus on the engineering content (which will still be valid in five years time) rather than on the exact delivery vehicle. If you need help mastering the latest technology seek help from your students and, if you have them, your children. This is co-operative learning (see above)! Alternatively if you have any influence on the budget of your School, suggest that the appointment of a learning technologist, to help you and your colleagues make best effective use of your time, would be a sound investment.

i. Simulation and games

Simulation is a key part of modern engineering. Our device circuits, our bridges, our aircraft, our ships, our cars, our chemical plant are all simulated before they are built. We cannot nowadays afford to do otherwise[3]. At one level you could argue that one of the important roles for an education in engineering is to enable our graduates to understand what lies behind these simulations, so that all of them understand their limitations, and a few of them can make better simulations in the future. This implies that we should stick to teaching the principles, not the use of the simulators. However there are many circumstances in which a simulation can be a very powerful learning tool.

[3] Our climate is being simulated too, for predictive purposes, although I am less than convinced that we know the parameters accurately enough to make this useful.

Many engineers will be familiar with finite element analysis (FE), computational fluid dynamics (CFD), computer-aided design and manufacture (CAD/CAM) and with the use of tools such as ProEngineer or AutoCAD. You may choose to teach your students how to use one or more of these in a rudimentary manner, although they are very unlikely to become truly expert (*see Chapter 4b*). You are likely to teach the finite element method, rather than how to use ABAQUS, Nastran or ANSYS, and you want your graduates to be aware of the capabilities and potential of computer-aided methods. However I do not consider these tools, important though they are, to be genuine teaching simulations. Neither does MATLAB – often called a simulation environment – meet the full requirements. It is often used to illustrate the effect of variables on engineering behaviour but usually in essentially mathematical or graphical terms. This is only partial simulation.

The full potential of simulations to support teaching and learning is realised when difficult and/or complex situations are simulated in order to clarify and explain – to accelerate understanding, not the immediate solution of problems. Simulations of this type are surprisingly rare, probably because they are time-consuming to write and the commercial return on specialised teaching materials is relatively low. (As low as on books like this!) However there are some very good examples out there.

Flight simulation is an obvious place to start. There are many simulators in university engineering Schools, ranging from PC-based versions with a single screen to research simulators with vast capabilities and high realism. Their appeal to students is obvious, although their attraction usually results from the student's enthusiasm for flying, not for engineering. Indeed it seems to me that few engineering principles are clarified by a flight simulator, although the scope for learning about control theory is significant. In my own university we use sophisticated simulators to help students learn about flight handling qualities, but not about many other aspects of aerospace or aeronautical engineering. They are principally a motivational tool.

Flight simulators do illustrate one of the key educational points about a simulation: In order to learn, it is essential that the student can determine and change the key parameters and thus interact fully with the simulator. A simulation is not the same as an animation.

Good examples of educational simulations include several examples of truss bridge simulators (e.g. DrFrame2D or West Point Bridge Design) which can be used in conjunction with practical exercises such as building cardboard bridges. They are configured as teaching tools in that they produce real-time responses as loads or structures are changed. A large-scale extension of this is the Constructionarium, at which students of civil or structural engineering build one-tenth scale models of real bridges, buildings and other large engineering structures. In this case simulation on the computer precedes, and is eventually validated by, the building of a real model.

Another very sophisticated and wide-ranging simulation tool is at www.steeluniversity.org This package of simulations of steelmaking processes was developed for use by both university students and steel industry employees and it illustrates many of the best features of an educational simulation, including:

- It deals with processes which, because of geography and danger, cannot be seen by most students;
- It was developed in close collaboration with steel company employees who are experts in their subject, so it is highly realistic;
- It offers the student the opportunity to control many parameters and to observe their effect, not just on the equations but on the product;
- It is supported by many (web) pages of background material, so that students can drill down for more detail or further explanation;
- It is associated with an international competition which increases student engagement.

Within steeluniversity, and the related MATTER site (www.matter.org.uk) are simulations of tests such as the Charpy and Jominy tests.

There are probably other good examples, but in my experience educational simulations meeting the criteria listed above for steeluniversity are rather rare. Electrical and electronic engineering is an area ripe with potential for simulations but a number of nominal ‘simulations’ have disappointing interfaces and outputs. For example SPICE (Simulation Program with Integrated Circuit Emphasis) originally required non-intuitive stacks of data, although more recent versions (e.g. 5SPICE) are somewhat more user-friendly and provide graphical representations of circuits. It would be good in many areas of engineering study to have more software which provided realistic, interactive and intuitive simulation.

There are also a number of simulations and games designed for school-level use, several of which can be found by searching the web sites of the Engineering Subject Centre and UKCME. Racing Academy is a good example of a competitive approach to teaching mechanics and dynamics (Darling, 2008). At this level a simulation does not need to be computer-based. Magill and Roy [2007] describe an exercise to simulate the fabrication of silicon devices using red ink, sticky labels and felt pens – low tech works well here and is very cheap.

When planning to use a simulation you need to think carefully how to ensure that the students learn rather than just play. Random clicking and changing of parameters might just reveal something interesting but this is frankly unlikely. Students need to be directed towards a simulation with a clear task in mind. You should at the very least ask them a question to which they can find the answer using the simulator. You also need to tell them that, if the simulation itself does not provide a facility for taking notes or recording their actions, it will be essential to record (possibly even on paper!) what they are doing as they proceed. In these circumstances a simulation can be extremely useful and thought-provoking, and the more inquisitive student will explore further and learn more (having taken ownership of this part of his learning).

Although it might seem that games for educational use will inevitably be computer based, this is not necessarily the most educationally-effective approach, nor the cheapest. Let me give one example of a simple cheap game which has been shown to make key issues in the optimisation of production clear and relevant to students. I owe this example to Laurence Legg [2010]. The game involves only paper, scissors and a stapler, and the artefact which is produced by the participating teams is simply two pieces of folded paper stapled together. This product could be referred to as a plane, a bridge, a chair or a Christmas card, depending on the class and the season. The manufacturing process is broken down into six or seven very simple operations, one of which takes much longer than the others. (When I did it the slow process was writing out the conference name on both sides of the 'fuselage'.) There are a few rules but the key learning outcome is the importance of a bottleneck in production (the 'drum' whose beat controls the output of the process). The teams can be taught the exercise in about 15 minutes and can then be given 15 minutes to plan their production line and 15 minutes to produce as many products, or make as much money, as possible. The whole exercise can thus be completed within an hour. The consensus among the teams of academics when I took part was that this exercise is best carried out before the key concepts are introduced to the class, so that they realise the significance of the dry stuff about scheduling. I could however also see value in doing it after some of the topic had been covered. There are surely many other examples of this type of approach in use – ask around.

j. Distance Learning

It is widely assumed that engineering, being a practical, largely experimental, subject, is unsuitable for distance learning. However it is worth questioning whether this needs to be the case. There is more to distance learning than the delivery of whole programmes to students living far from the host university. The key characteristic of distance learning is very limited attendance of the student at the host institution. This usually (but not necessarily) implies;

- Access by the student to learning materials which might be on paper, on line or on portable media;
- The facility to study at any time (non-synchronously) and at any pace;
- Access to an on-line discussion/tutorial group of fellow students;
- Occasional on-line access to a tutor;
- On-line formative assessment;
- On-line or conventional summative assessment.

These characteristics can be applied to a single module, or even part of a module. This can offer a number of advantages such as;

- reduction of timetabling constraints;
- reduction of student travel time;
- reduction of time constraints so that a module could be studied at any time, e.g. for re-sit purposes;
- parallel use of a single module for locally registered and remote students;
- study of one or more modules by students on exchange schemes, work placements or field trips.

Edirisinga and Fothergill (2009) report an example of a single module (in this case 'Optical Fibre Communications Systems') delivered in an on-line environment which includes e-lectures, podcasts, video clips, animations, quizzes, background reading, links to other web sites, summative assignments and a discussion board. Removal of timetabling and room booking issues meant that they were able to package each e-lecture and podcast as a 5-10 minute segment. The e-lectures could be repeated in successive years while the podcasts were up-to-the-minute, recorded afresh every couple of weeks to ensure currency. As with many newer techniques, after the set-up effort had been expended the running costs of the module were not markedly different from those of a conventional face-to-face module, while student reaction was positive.

k. Assessment of Learning

> A question: How should you score the pentathlon? What is the 'correct' way to add times and distances?

Deciding on the assessment techniques for your module or course should be the second activity in the constructive alignment process, after defining the intended learning outcomes and before considering teaching and learning approaches. There are of course many ways of assessing students – certainly many more than the closed-book end-of-module examination and the fortnightly piece of 'coursework'. The box gives a list as an aide memoire.

- Closed-book examination;
- Open-book examination;
- On-line test, involving some or all of:
  - Multiple-choice questions (MCQ) with single or multiple answers;
  - Word-completion exercises;
  - Numerical questions;
  - Randomised questions;
  - Clicking on images;
  - Selection of a few questions from a larger bank;
  - Hints;
  - Feedback;
- Oral presentation with or without questions;
- Oral examination on a predetermined topic;
- Oral examination on open topics;
- Written report (with or without a pro-forma);
- Designs or manufactured artefacts;
- Poster or e-poster;
- Assignment involving numerical or essay questions;
- A portfolio of work, or an e-portfolio;
- A wiki.

When devising assessment tasks you should bear in mind a few questions:

- Is this assessment formative (they learn from it) or summative (they get a mark for it)? Could it be both? Even if it is summative, should the students have their script or other work returned, so they can learn from it or even cherish it? I would argue that even the final undergraduate exams are merely the start of life-long-learning, so need to be formative;
- How are you going to give feedback to the students? Can you do this individually or must it be generic? How long after the hand-in date can you provide feedback? [*see below*];
- Do you require the same 'pass mark' for all material, or are there some elements which it is essential for the student to know or understand? You might assess 'core material' differently (e.g. with a local 100% pass mark), either within a single examination or separate;
- Is your motive in setting this assessment to allow the students to demonstrate competence (without which they should probably not be allowed to practice), or to differentiate the smart from the average, so that you can label them differently on graduation (first vs lower seconds)? Or to give credit for further non-directed study?;
- Could you (while maintaining fairness) use a multiple-choice (MCQ) or multiple-response format which could be set in e-form and would not need to be re-invented next year?;

- Could you use questions from a question bank, either of your own devising or offered from elsewhere?;
- Have you considered getting the students to write their own assessment questions and tasks? This is a very good learning experience for most students;
- Are you testing knowledge or understanding (or other levels of the Bloom taxonomy – *see Chapter 2*). If you are not simply testing recalled knowledge, could the students reasonably have books and notes available? Do they need a hard time limit?;
- Could some of the assessed items be gateways to further study or achievement? In other words they could carry zero 'marks' but a pass could be required before further material or summative assessments are released.

You might wonder why, at least in the UK, we expect students to write by hand in most exams whereas we demand word-processed text on almost every other occasion. It should be no surprise that it is often difficult to read exam scripts.

Multiple choice questions (MCQs) are of course very attractive in principle because they eliminate much of the chore of marking and are ideally suited to delivery on-line. However before you rush off and re-write your exam in this form, it is worth considering some of the pros and cons. Good MCQs, which discriminate between students who understand and those who do not, are not easy to write and will take time. But of course you can use them again. Before you start, find out whether your institution offers on-line testing and/or paper-based forms which can be machine-read. Increasingly you should have available a system which enables you to:

- Ask a variety of question types;
- Expect single or multiple correct answers;
- Allocate different marks to different questions (so that you can mix short and long tasks);
- Analyse the distribution of answers to each question.

If you have all this available then try to write your questions so that:

- There are no 'silly' answers which can be eliminated as obviously wrong. This is actually rather difficult and you will spend most of your time composing plausible wrong answers, both to qualitative and numerical questions;
- You learn something about the misconceptions of the students, to inform the development of your class next year;
- You are able to differentiate between understanding and recall.

Because the MCQs are computer-marked you will usually have better data about the range of student performance than for a conventional exam. This enables you to weed out those questions which either all or none of the students get right, and to adjust your teaching in future. If you are seeking only to differentiate the students (and are willing to forgo the formative aspect of the test) then you can probably find just a few questions which regularly divide the students into those who get it and those who don't. Being cynical, at one level, that is all you need and it would be provided by a very short exam.

Life is an open-book exam

A radical but very stimulating method of oral assessment has been practiced for more than 20 years in the discipline of Electrical Engineering in the Faroe Islands [Jensen, 2010]. Students are given 60 minutes to prepare a presentation on a whiteboard and twenty minutes to explain and defend it to two members of staff. A list of twenty or more potential topics, spanning the syllabus, is published at the start of the module, and the students do not know which of these they will have to present until they enter the examination room. This style encourages the students to prepare across the whole syllabus, and allows the examiners to explore understanding as well as recall. It works well for modest-sized classes (at twenty minutes per student you can assess twenty or so students per day) and there is almost no time required to devise the assessment, so this is the total time commitment for assessment.

Finally – a comment about the re-scaling or other adjustment of the marks from any assessment instrument. It is quite common for examiners to re-scale sets of marks, usually when the mean or distribution of the marks seems to be much higher or lower than expected. There are many ways of doing this, despite a dearth of papers describing them, but the more important question to address is <u>why</u> you might be doing it. The only serious justification I have heard is the pragmatic 'surely we are not going to fail this large fraction of this cohort' (in response to a particularly low set of marks). This is of course no (educational) justification at all, although it might be a realistic response to financial pressures!

So where scaling is used, is it a short-term fix to ameliorate the effect of a poorly-devised exam or a badly-taught module, or is it part of a strategy to avoid the distortion of a student's average grades by a small number of 'anomalously' high or low marks? I can find no serious, thoughtful, writing on this subject but I have been told by respected academic friends that some cohorts of students, of equivalent entry standard, although apparently taught the same material in the same way and having been set an exam closely similar to previous years, nevertheless deliver radically different sets of marks. My own thoughts on this behaviour are:

If the cohort was of very different ability or put in a very different amount of effort, then their ‘anomalous’ marks should surely stand.

But perhaps the assessment instrument (e.g. exam) has a very large random noise element and an error bar of perhaps +/- 10 percentage points - in which case surely we should work to improve the assessment instrument and/or average a lot of such sets of ‘uncorrected’ marks.

In neither case is re-scaling justified, in my opinion. A potential explanation for the anomalous behaviour might arise from the group dynamics of a class of students. It is often reported (anecdotally – I have not seen the hard evidence, but I don’t read much sociology) that the behaviour of a whole group can be influenced to a significant extent by a few opinion leaders. It might become the accepted wisdom among a particular year group that a particular module is ‘difficult’ or ‘not worth the effort’. It might also happen that a key threshold concept (*see Chapter 2a*) is not mastered by the group leaders and thus is not effectively transmitted around the class. These might be interesting issues for future educational research projects, but it is difficult to see why one should manipulate exam marks to deal with them.

l. OSCEs/OSTEs

Most medical students undergo practical examinations known as OSCEs – Objective Structured Clinical Examinations. In an OSCE, each student completes a set of closely defined tasks, in a circuit of half a dozen different stations, and is objectively marked (usually by an observer who does not know them) on each one. Typical 5-minute tasks might include measuring a patient’s blood pressure, conducting a spine examination, taking a cervical smear or explaining how to use an inhaler.

There is plenty of scope for the use of such a carousel of tests in engineering, but I can find little evidence that this approach has been incorporated into the assessment regime for an engineering programme. The only report of such tests in the UK comes from Alinier and Alinier (2005) from the University of Hertfordshire. They called their technique Objective Structured Technical Examination (OSTE). Alinier and Alinier devised and tested 16 stations in the area of Electrical and Electronic Engineering. Their tests, both theoretical and practical, included the use of an oscilloscope, the identification of RF frequency bands, the use of logic gates and the construction of a simple circuit on a bread board. The evaluation of the students was that OSTEs were an excellent and helpful formative tool, but they were less keen on their use for summative assessment. Staff, on the other hand were almost equally positive about the formative and summative uses of the OSTEs.

The OSTE idea is clearly applicable across the whole range of engineering disciplines, especially if you accept that the exercises can be both practical and theoretical. In the early years I could imagine testing the use of a micrometer, the plotting (or interpretation) of data on log paper, various measurements and their error bars, the interpretation of microstructure and many more.

m. Feedback

In surveys of student satisfaction in the UK in the years 2005-2010, one of the most consistent problems identified was that of inadequate feedback on assessment. This simplistic statement hides a number of potential issues. What do we mean by feedback? What do the students consider to be feedback? When should they receive it?

A straightforward attitude would be that students deserve feedback on all work which they submit, and they need it in time to act on it before they make the same errors again. The implications of such a policy might include:

- Teachers should clarify the nature of 'feedback' while being open with their students about the difficulties of providing it;
- Feedback might take the form of:
    - written marginal comments on each piece of work;
    - boxes indicating common errors ticked on a cover sheet;
    - verbal feedback to the next meeting of the class;
    - comments posted on the module VLE;
    - exam scripts returned with indicative answers;
    - tutorial sessions;
    - peer marking against a set of criteria;
- Feedback should include comments on positive as well as negative points. Students need to know 'Why did that get such a good mark?' as well as 'Why did I get such a poor mark?';
- The timeliness of feedback is a constant concern. Many universities now have a guideline response time of about 3 weeks. In my view this is too long, especially in engineering where much learning is consecutive. You might like to set yourself a target response time – say one week – and then consider what method you can use within this timescale, given the class size and the amount of assistance available to you. I know that this sounds pious, but it must be true that if you are going to give feedback, then it takes the same total time whether you do the work over one week or three. Since it is more useful for the student in one week, when they have a chance of being able to remember the exercise, this should be your target;
- Staff need feedback too. Teachers need to know what was difficult and what was easy, and ideally <u>why</u> common errors or mis-conceptions occurred. You should regularly ask feedback questions (e.g. at the end of a test, as suggested above) and review the errors students make;
- You might need to argue with your examinations officer or university procedures in order to return marked exam scripts to students. My

view is that students deserve feedback on their exam performance, in order to improve their approach to the next semester or year, or to the life-long-learning they will engage with immediately on graduation. You will have to contend with colleagues who will assert that feedback is unnecessary on summative assessments such as end-of-module exams. Tell them that this is nonsense – all assessment should be formative.

There is an emerging view that we might be placing too great an emphasis on feedback, at least in the forms I have described above. A view espoused by Royce Sadler (2010), and which seems to me to have a lot of merit, is that most feedback (for example marginal comments on a piece of written work) suffers from two key drawbacks:

1. The student may not understand what you mean (even if you think it is straightforward, such as 'this does not follow from what you wrote earlier'); and
2. You are essentially 'telling' the student rather than involving her. This is the antithesis of the active learning which I have championed in the rest of the book.

The first point is worth expanding further upon. You and I, as assessors, see hundreds of pieces of submitted work and have had the chance to develop a quite sophisticated and subtle appreciation of the strengths and weakness of student submissions. We are therefore internally calibrated and are constantly making comparisons. We know what a 'good' answer looks like, and a bad. We know that there are many ways to get it 'right' and many ways to get it 'wrong' (whatever 'it' is). The student has probably only ever seen a single example, her own submission, and is unlikely to recognise the potential range of answers. There is a strong case for peer assessment, just so that each student gets a chance to see a range of submissions of different quality. You probably want to anonymise submissions before circulating them to students, but this also gives you the chance to mix in an example that you have written yourself, or a good answer from a previous year. Sadler also suggests that you do not issue marking criteria to students. This rather counter-intuitive advice acts to force the students to consider for themselves what it is that makes a piece of work 'good'. If you took my earlier advice and read Zen and the Art of Motorcycle Maintenance you will recognise this strand of thought.

The second point is also worth further consideration, although solutions are rather difficult. You might feel that the best way to introduce 'active' feedback is to discuss the work with the student. However you are unlikely to be able to make the time to do this, especially with large class sizes. In such cases one of your only options is to get students to share and assess their peers' submissions. This is probably best done in groups of 5 or 6, and can then be carried out almost in real time. A further possibility is to assess using a tool which provides instant feedback, such as Pearson's Mastering Engineering resources (2010).

n. Personal Development Planning (PDP)

All UK universities are strongly encouraged by their funding bodies to offer PDP to their students. Personal development planning encourages the student to reflect on his learning, his achievements and his career development goals.This can be supported by paper-based or electronic recording systems, either of which can in principle be carried forward by the student beyond graduation and could form the basis of a record of life-long learning. As well as encouraging the student to think about what they are engaged in, this is also useful for eventual registration as a professional engineer.

Despite these clear advantages, it is usually difficult to persuade students in the early stages of their studies to take the process seriously. Academic staff are often urged to stimulate student interest, for example during tutorials, but it might be more effective to involve external industrial friends and alumni in pointing out the usefulness of the exercise and the potential importance of PDP.

There is a comprehensive guidance document about PDP on the web site of the QAA, at http://www.qaa.ac.uk/academicinfrastructure/progressFiles/guidelines/PDP/PDPguide.pdf

o. Closing remarks

Whatever your chosen teaching method, you almost certainly want your students to engage wholeheartedly in their own learning. I recommended, in *Chapter 2g*, Elizabeth Barkley's book on Student Engagement Techniques (Barkley, 2010). It is worth listing here some of the tips she advocates, as ways of promoting student engagement. The following list is taken, selectively, from her contents pages: You can read fuller details in her book. The techniques apply across virtually all teaching methods; the bold emphasis and italic comments are mine:

- **Expect** engagement; *(if you do not expect an engaged attitude, you will almost certainly not get it);*
- Reward learning rather than behaviour; *(e.g. give marks for understanding something, not for turning up at the session);*
- Promote student autonomy;
- Teach things worth learning; *(not as easy as it sounds!)*
- Devise **engaging** learning tasks; *(to be successful at this you may need to investigate what it is that your students find engaging. This is almost certainly not the same as what* ***you*** *find engaging!);*

- Try to rebuild the confidence of discouraged and disengaged students;
- Clarify **your** role; *(e.g. I'm here to help you learn and understand, especially the difficult bits, not to tell you how to answer exam questions);*
- Help students develop learning strategies; *(e.g set some reading with critical thinking outcomes – see Chapter 4c);*
- Activate prior learning; (*e.g. from other earlier modules);*
- Teach for retention; *(not for short-term memory, with the exam as a memory dump);*
- Limit and chunk information; *(i.e. structure the material you wish the students to understand in accessible amounts. There is no shame in bite-size information, as long as it forms part of a coherent overall structure and pattern, set by you!);*
- Do not adopt an authoritarian role; *(you should expect the students to be your intellectual equal. If you are sometimes disappointed, don't let it show!);*
- Reduce anonymity – learn students' names and help them learn each other's names; *(this is difficult in large classes, but you might be able to use technology, e.g. clickers or a spreadsheet containing a class list, to help you);*
- Be consciously inclusive; *(e.g. make a particular effort to involve students who are usually silent);*
- Subdivide large classes into smaller groupings; *(sometimes, not all the time);*
- Assess the starting point for your students; *(do you really know what they have learned, or been exposed to, in previous modules? Do you know the range of prior attainment in the class, especially for first year classes who have entered from a variety of previous establishments?);*
- Help students learn to self-assess; *(peer marking is one way they might be helped to do this, but critical thinking tasks can also be helpful);*
- Offer options for non-linear learning; *(why should all students wait until you are ready to expose the next topic later in the module? Might some of them not enjoy getting ahead right now, in parallel rather than in series with your current topic?);*
- Include learning activities that involve physical movement; *(no, not the launching of paper planes, unless you are teaching aerodynamics);*
- Consider creating a **graphical** version of the syllabus; *(so that the students can more easily spot the relationships among your various topics. It's interesting for you too.).*

Good luck with all this.

What you might take away from this chapter:

- An appreciation that there are very many ways of encouraging active learning and understanding;
- An understanding of several ways of enlivening a class even when it is held in a lecture theatre;
- The challenge of devising assessments which are aligned to the learning outcomes and which test understand and deep learning as well as recall and surface learning.

Testing of Formula Student racing car

Chapter 6: Some commonly-raised issues

a. Attendance at classes

It is a common complaint of engineering lecturers that attendance at their lectures rapidly drops from near 100% for the first lecture to a steady-state value between 40% and 60%. There is also a good (but not perfect) correlation between attendance and exam performance. The fundamental reason for low attendance is absolutely clear. Students attend if and when they believe that they will get something useful from the experience – or at least get more than they would from any competing activity. A survey conducted by Tim Bullough in 2008, among a large cohort of students, elicited the following comments on lecturers who were regarded as excellent:

- Enthusiastic, passionate about the subject; knows his stuff;
- Lectures are clear and well-structured and the material is presented in a clear logical way;
- Notes are well set out and easily understandable;
- He explains things very well;
- Lots of practical, real-world examples;
- He interacts with us in lectures;
- He does not talk down to us;
- He is very helpful, immediately responding to email enquiries;
- He is very approachable and showed real concern for my learning;
- The learning objectives were very clear;
- He makes sure that the class understands the problem.

None of this is surprising or sophisticated – it's just common sense.

One further thing you can do to minimise the risk of non-attendance is to schedule deadlines for course-work and reports carefully. Avoid, and ask your colleagues to avoid, deadlines during the working day which can compete with scheduled lectures. Why not set a deadline of midnight on a Sunday (or even a weekday) so that the last-minute brigade neither needs to skip your lecture nor to stay up all night?

There is also an issue with late arrival at classes. Locking the door at the scheduled start time has been used by some lecturers but is usually unacceptable for safety reasons. The key point is consistency – the same treatment should be given to all late students on every occasion, and the reason for your intolerance of lateness should be explained clearly. For me, it is the discourtesy to other members of the class, whose concentration (as well as mine) is disturbed by late entrants.

b. Resources to support teaching and learning

There are many sources of materials to support the teacher and the student. The most obvious are textbooks – on paper or on-line – and web sites. I recently (2009) interviewed two graduates who obtained first class degrees from a major UK university: They asserted that they did not open a single paper text book during the four years of their programme. They had used many resources, but paper-based text books were not among them.

One source of resources is becoming available through the work of several projects on Open Educational Resources (OER). For several years MIT has offered its Open Courseware [http://ocw.mit.edu/] and the Open University in the UK has OpenLearn [http://openlearn.open.ac.uk/: Look under Technology as there is no separate Engineering section]. The OER projects have tried to ensure that there is a single portal for each discipline which leads to resources of all types which are openly and freely available under Creative Commons licenses. This means that you can use, distribute and even modify other people's educational resources as long as you do not sell them on. There is a single repository for all these in the UK, called Jorum Open [www.JorumOpen.ac.uk] as well as subject-specific gateways which might be simpler to use [e.g. http://www.engsc.ac.uk/oer and CORE-Materials core.materials.ac.uk]. Resources available from these sites include photographs, videos, lecture notes, questions, animations, simulations and even in some cases whole books. This book is itself available as an OER.

There are plenty of other resources, many of which cannot be accessed through a single site or URL. Among these are www.engineering examples.org which contains active ideas for mechanical engineering teachers.

Appendix 1 includes a fuller list of resource sites.

c. The spaces we teach in

Of course most of us have to teach in the only spaces available to us. However just occasionally there is the possibility of designing new spaces, or converting existing rooms. In these cases you need to consider carefully what you want.

The raked 'lecture theatre' is aptly named, and is a good place for theatre. If the lectures you want to showcase are that good, then use a lecture theatre. If you want your students to be active, then you (and they) will find a forward-facing, side-by-side, one-to-many environment quite unsuitable. Since 'activity' can take a large number of different forms, we probably need spaces which are very flexible. In designing the Active Learning Labs at Liverpool I briefed the architects with the phrases ‘nothing is to be bolted to the floor’ and ‘I cannot tell you what the space will be used for because others more imaginative than me will do different things over the probable forty year life of this building’. The architects didn’t like this brief, but that was their problem! I ended up with large open, flexible spaces. Later I learned of other approaches with similar benefits – several new teaching spaces in other institutions use internal glazing to great effect. It helps tremendously with changing the attitudes of both staff and students if they can see what is going on. Why should teaching and learning – and making and doing and communicating – not be visible? (Although one colleague commented that he does not want visitors – particularly teachers or parents – to go away with the impression that active engineering is all about being a mechanic, just because he caught sight of a student in overalls working on a car.)

Other features that you will probably need to consider (and you will almost certainly not be able to afford enough of any of them) are:

- Small break-out rooms, bookable by both staff and students, for team meetings, seminar practice, tutorials, presentations to sponsors etc; And an easy-to-use booking scheme for every space;
- Storage for work in progress, the best of last year’s constructions, tools, experimental kit not currently in use and so on;
- Space for students to store (locked up!) their safety equipment, coats, bags, computers, lunch …

d. Assessing individual students in team work

The issue of assessing individual performance during group or team work excites a lot of debate at meetings of academic engineers. Setting aside the practicalities for a moment there are two key questions: How can you be fair to individual students without imposing an unacceptable workload on either the students or yourself? How can you ensure that all students meet all the learning outcomes defined for the team exercise? These two questions should make you consider carefully a) what learning outcomes you set, and b) how much help, whether human or technological, is available to you. I cannot solve those problems for you, but I can give an idea of the range of techniques available:

Among the assessment techniques you could use, whatever the task and the assessed output, are:

1	Assigning a group mark and giving it to every member of the group	This requires the least effort but might be the least fair to an individual
2	Assigning a group mark and allowing the group to moderate it by mutual agreement (perhaps by up to 30 percentage points) for each member, as long as the overall group average is maintained.	This requires group buy-in and some effort from them (but not much from you). The exercise of negotiating how to apportion a fraction of the marks is a good learning experience for the students.
3	Assigning individual marks to each student, based perhaps on your observation of the group work and a separate oral or written submission from every student.	This is very hard work for you, and almost impossible if the number of groups is large. It can be made easier if there is a single final group report, with the author(s) of each section clearly identified.
4	Assigning a group mark, but moderating it for each student based on input from all other students in the group.	This sounds complicated and would require a lot of paperwork, but is manageable using software such as WebPA, [http://webpaproject.lboro.ac.uk/] which largely automates the processes and permits anonymous marking of students by students (or it can be transparent if you wish). Students can lean a great deal from seeing the comments of their peers on their contribution.

e. Enlivening large classes

If you employ one or more of the techniques described in *Chapter 3* your classes are probably already lively. If not – read on:

The role of humour

I am a fan of the light touch. Not everyone finds humour easy to inject into a lecture, but it is worth considering some of the advantages: It breaks up the lecture, ensuring that students are awake (I'm not entirely joking); it may provide memorable moments, helping students to recall particular topics; it provides opportunities to relate your subject matter to issues outside the class room. Don't worry that you might be sending a message that your subject is not to be taken seriously – there are plenty of opportunities to demonstrate how serious you are about engineering and your part in it. Humour, if sensitively done, also provides an opportunity to demonstrate to overseas students the 'English' perspective on life. In my view a mature engineer should be able to step back and look quizzically (and therefore critically) at their discipline.

Walk about! Make yourself visible as an accessible human being to all the students by moving around the lecture room or theatre either while speaking or while the students are engaged in tasks.

Try to learn as many names as possible, or at least have a class list and select random names to answer questions, not just the faces you recognise or those sitting at the front. If you have a clicker system you may be able to use this to identify and call on random (but named) students.

And finally – be passionate and responsive. If your passion for engineering is not palpable, how do you expect your students to catch it? If they do catch it, they will want to engage with you, so you must respond quickly and enthusiastically.

f. The 'level' of a module

The issue of assigning to every module a 'level' (effectively 'first year', 'second year' or whatever) is fraught with difficulty despite being demanded by many national agencies in higher education. To make matters worse there are at least half a dozen different systems, variously using numbers (Levels 0 to 3, 1 to 8, 1 to 10 or 1 to 5) or letters (Levels C, I, H, M, D). The most recent of these [2010] is the European qualifications Framework, EQF [http://ec.europa.eu/education/lifelong-learning-policy/doc44_en.htm]. You need to be an expert to decode any these systems, let alone use them. Jenny Moon describes the historical background very clearly:

'A programme in higher education used to be described in terms of years – thus we would talk of a student in her first, second or third (or may be fourth) year of an undergraduate programme. Generally the reference to years of study would convey the complexity of teaching, and the demands of learning and assessment that the learner would be experiencing. While the patterns of higher education were in their traditional form, this system was adequate. For example, there were relatively few students – well under ten percent of the population – and nearly all were full time. Those students did not tend to change between programmes, and teaching and learning was integrated and not modular. Under these circumstances, we assumed that we knew what a second year student's work looked like. Whether or not we could have agreed on this in a precise manner might sometimes be debatable. When the matter of expectations of student achievement was addressed, we would rely largely on the interactions between teaching staff and external examiners to sort it out. Evidence of this approach to levels is demonstrated in the Council for National Academic Awards Handbook (CNAA, 1991) in which Level 2 achievement is simply described as 'Work equivalent to the standard required for the fulfilment of the general aims of the second year of a full-time degree'. Such a self-referential approach does not enable the development of an agreed concept of standards.' [Moon, 2002]

Unfortunately the acid comment about self-referential statements applies in several other areas of higher education. We are usually exhorted to set masters-level problems, for instance, without any clear agreement as to how these might be differentiated from 3rd-year problems or 1st-year problems. We are supposed to know a masters level problem when we see one, but I'm not sure that I do! I must admit that my response to a demand to assign a level to a taught module is simply the path of least resistance: If it is to be offered largely to second year students I call it level 2; if to Masters students I call it level M. There seems to me no satisfactory way of assigning a level to a topic which is being met by the student for the first time. I used to teach crystallography. I would have to cover the same concepts and techniques whether I was teaching it to undergraduates or to Masters students. In both cases it would be entirely new to them. The only way I might differentiate would be to go faster for the Masters students (but this does not necessarily work – I'm not convinced that Masters students pick things up more quickly than undergrads). The same argument would apply if one was teaching Greek as a new language to Archaeology students – how can the level be different if it's all Greek to all of them? So let's waste no more time on level descriptors. If you are excited by such things, read Jenny Moon's very sensible (but intrinsically boring) paper [Moon, 2002].

g. How do we know we have improved anything?

This is one of the hardest, and most frequently-asked, questions. There are some straightforward, but not very convincing, answers and some more honest responses. I will mention both.

I have already referred to a couple of positive surveys by Strobel and van Barneveld (2009) on project-based learning and Hake (1998) on active learning. Evidence like this is thin on the ground.

Simplistically you could look at the assessed behaviour of your students - at their exam results and/or their other assessment performance. You might feel encouraged if the average grades of the cohort improve year by year. However you should also ask yourself some hard questions such as 'did this cohort actually have the same innate ability as previous cohorts?' and 'were my assessments or exams equally challenging this year as in previous years?' or 'did anything else change for these students, for example what they learned in some of my colleagues' modules?'. I have never been able to answer these questions for myself with absolute certainty, and I doubt that you can.

Alternatively, or additionally, you could consider other – more qualitative – indicators. Did you get better questions from the students during and after lectures this year? Are your colleagues commenting more favourably about some or all of these students, or the skills and knowledge they bring from your class to other classes?

Thirdly, you might consider the student responses to your mid-module feedback questions or end-of-module questionnaire. In constructing these, and then considering the responses, you need to distinguish clearly among: did they like me and my presentation?; did they like the topic?, and did they learn what I wanted them to learn? Only the third of these is really important! (Although the other two might help you achieve the third.) Remember that end-of-module questionnaires are often referred to as 'happy sheets' and I overheard a prominent engineering educator comment 'questionnaires measure charisma, not education'. You could improve this situation by asking 'how could this module be improved?' and making sure that you feed back the results to the students. You might, as a programme director or Head of School, consider whether student questionnaire results should be publically available.

Those were the conventional 'easy' answers. The less palatable but more honest answer is that you really cannot measure your success in changing your teaching methods, at least until a very long time has elapsed. You might get positive reinforcement ten years later from a graduate who tells you she always remembers your explanation of widget design and it helped her at work recently. However if you get more than one or two of these a year, you are doing very well indeed, so it is not a rapid feedback mechanism!

To be more encouraging there are a number of indirect ways of reassuring yourself that you are doing a good job. Firstly – trust your own judgement. You made changes because you were convinced a while ago that this was a good idea. It probably still is. Secondly, trust your colleagues across the world: You will probably have colleagues within your School who encourage you and share experiences, but there are also networks such as the HEA Subject Centres (in the UK) or the Australia Learning and Teaching Council (ALTC, formerly the Carrick Institute) or the CDIO network internationally. Fundamentally you have to know in your gut that you are making changes to improve the learning of your students. If you don’t buy into this there is nothing I can write which will change your mind!

In summary ask yourself ‘will doing it this way produce better engineers (or scientists)?’

h. Keeping enough time for research

It is of course very important to many readers that your technical engineering research does not wither simply because you are enthusiastic about improving the quality of your teaching and your students’ learning. And there is no reason why it should. Your attitude towards both aspects of your work is likely to be the same – you want to be the best in the world. Your approach to this ideal is limited in both cases by the same two factors – the quality of your ideas and the time you are prepared to give to them. The tools you have available are also the same – time management and networking. My recipe for success in both fields would be the same – talk and listen to lots of other people, and partition your time equitably between teaching and research. If you have a ‘research’ day you no doubt expect to spend time in the laboratory, time with your research students and time writing (notes, papers or grant proposals). If you have a ‘teaching’ day you expect to spend time in a class room, time with students and time writing (notes, papers or grant proposals). My advice is: Do not stint on either activity. Value your time with undergraduates as highly as you value time with postgraduate students or postdoctoral researchers. Keep your appointments in both cases! If you have advertised ‘office hours’ then keep them and be there. Additionally, use technology to help you. I kept all the papers I consulted during the preparation of this book separate from my electron microscopy collection in a useful piece of software called Mendeley. Using this I could consult my most-needed resources from anywhere in the world, and it has a great search facility.

In both activities the best is the enemy of the good (I know it’s a cliché; Voltaire in the 18th Century, if you are wondering). If you strive for perfection in either field you will consume all the time you have available and risk not producing some very good work. It is almost a certainty that you will not win a Nobel Prize, whether you spend two days per week on research or seven, nor become Minister of Education whether you spend two days a week on teaching or seven. So relax, enjoy both and do the best job you can in two days per week each. That leaves you with one day per week to cope with your administrative load and the weekends to play with your family (or race your motorbike). You will increase your chance of living to 90 and enjoying it.

i. Getting promoted

Promotion is important for the individual and for the institution. It gives you a reward for your commitment and effort, and it allows the institution to encourage helpful behaviour. The criteria for promotion, whether written or unwritten, are set by the employing HEI. Cases based on excellent contributions to teaching tend to be difficult to make compared to research cases, where the two proxies of grant income and refereed publications are readily available. However there are a number of ways in which a teacher can demonstrate his or her impact at national or international level, as would be expected of a researcher. Evidence should refer primarily to activity and recognition which goes beyond the candidate's employing institution. Among these are:

Publications

- In education journals (J Eng Ed; Engineering Education; EJEE; IJEE; J Mats Ed etc);
- In conference publications (there are many conferences on Engineering Education) organised by ASEE, SEFI, the HEA for example;
- Textbooks authored;
- Educational software written, with evidence of use elsewhere.

Invitations to speak

- Seminars and workshops at other institutions;
- Keynote and plenary presentations at conferences;
- At Subject Centre or HEA events;
- At events within your own institution.

Prizes and awards

- From professional bodies;
- National Teaching Fellowship (in the UK);
- Internal teaching awards.

Professional recognition

- Fellow or Senior Fellow of the HEA.

Funding

- Educational research grants;
- Major awards such as CETLs (Centres for Excellence in Teaching and Learning) and other initiatives as they come along;

- Small grants from e.g. HEA Subject Centres.

Leadership and managerial experience
- Directorship of L&T at School, Faculty or University level;
- Programme Director positions;
- Professional body Accreditation Panel membership;
- External Examinerships (*see 6c* for a further discussion);
- Internal leadership of accreditation bids;
- QAA Assessor or similar experience;
- Specific role(s) within Subject Centre or CETL.

There is a very thoughtful and comprehensive guide to the evidence you might collect when making a case for promotion on the University of Wollongong web site at http:\\focusonteaching.uow.edu.au/ evidenceforpromotion/index.htm

j. The cost of improved teaching

As I write this section the UK is just (I hope) emerging from recession and the newly-elected coalition government is considering how to take more than £10^{11} out of the economy. This will undoubtedly involve reducing the per-student central spend on universities. There is a parallel working group (led by an engineer, Lord Browne) looking at the possible level of student fees in the UK, but it seems politically unlikely that this will result in a higher amount being available to teach engineering undergraduates. I mentioned earlier (*Chapter 4d*) the RAEng study which resulted in the Report 'Engineering Graduates for Industry'. This group found it difficult to identify the true cost of an engineering education, but let's put that on one side and consider the items you would need to fund in order to be able to improve engineering education in some of the ways implied in this book.

Assume that you are responsible for the delivery of two modules, each with 50 students, and that this represents about a quarter of a student-year (i.e. the students take 8 such modules in a typical year).

Student using a flight simulator

	Cost, £	Cost per year £	Cost per student per year £
A teaching assistant (TA) or vacation student to help revise your module – say once every 5 years	3000	600	
A TA to help with marking and feedback	250	250	
Software licences for those few good products which are not open	1000	1000	
Travel to and attendance at one network (e.g. CDIO) meeting per year	1000	1000	
		2850	
Multiply by four (for the other ¾ of the student year)		11400	228
Real materials for design-build projects (not needed for every module)	5000	5000	
A set of clickers for 50 students (useful for all modules)	2500	500	
Refurbishment of teaching spaces to provide more flexibility (20 year life)	200000	10000	
		15500	310
Grand total			538

So the true cost at School level of greatly enhancing the students' learning experience is around £500 per student per year. This is not a lot, in the context of the total cost of between £10000 and £15000 per student per year. It is an increase of 5% or less. Even in the UK context of Full Economic Costing (FEC) this implies an increase in the fee required to study engineering of about £1000 per year. I make no comment on the political reality of achieving this.

What you might take away from this chapter:

- Good teaching requires your commitment, but it also needs resources such as space, teaching assistants, on-line materials and networking. You should therefore be prepared to make a persuasive case within your School for a budgetary allocation which recognises this;
- You should trust your own judgement on many issues of quality;
- It is perfectly possible to be internationally successful at both research and teaching, but you will need to manage your time well;
- The additional cost of greatly improving the learning experience for an engineering student is rather modest.

Students building a cardboard bridge

Chapter 7: How to change

It is widely appreciated that anyone proposing a change to the *status quo ante* is first regarded as mad then, if he persists, as bad – with intent to destroy all that is finest about current activity. Finally, when the innovation has been incorporated successfully, the innovator's status declines to someone who merely stated the obvious. Recognising that this is likely to be the fate of anyone still reading this book – you must have found something to agree with to get this far – I offer in this chapter some practical suggestions for encouraging change, and also some ideas which at present would probably get us branded as mad or bad. I'm old-fashioned enough to believe that one has a duty to try to change the world for the better, and the only world I know much about is that of higher education. So, in order of increasing difficulty, let us consider changing the behaviour of students, staff and university systems.

a. Students

Students are usually quite conservative, but we currently have a couple of huge advantages. Despite prolific efforts at publicity by HEIs, and energetic social networking among students, most incoming students are rather badly informed about the programme they have entered, but they are on the whole prepared to believe that university will be different from school (and it certainly should be!).

The consequence of these advantages is that teachers have one opportunity, at the beginning of each student's programme, to set standards and encourage behaviours which are different from those which went before. If we wish to establish student ownership of their own learning, independent attitudes to study and the beginnings of professional behaviour we have to encourage (or even demand) these from the first day. The content of the first year syllabus and the choice of teaching and learning methods is paramount in establishing habits of study and professionalism which have to last not just four years, but a lifetime.

I would like an engineering education to demonstrate some of the attitudes which my son encountered when he went to music college: He was expected to act as a professional musician from the day he entered the door. He had to have a good instrument (his responsibility, not the college's), turn up for all activities (especially orchestral rehearsals and performances – for which he would have to arrange a substitute if he was ill or injured) and dress appropriately for performances (owning his own dress clothes). He did these things for two key reasons; Because he keenly wanted to be a musician and because it was expected by the staff who taught him. I can see no reason why we should not and could not have a similar set of expectations of engineering students. They need a computer (not a trombone), they need to attend or arrange replacements (for their team and group work) and they need the appropriate dress (safety gear rather than a dinner jacket). These are probably less onerous requirements than those imposed on music students, so why don't we impose them?

So, returning to some of Barkley's points (2010) discussed in *Chapter 5m*, you should try to:

- Talk, and listen, to your students;
- Tell them you expect them to be engaged, and explain what you are prepared to do to help them;
- Set and maintain high standards.

b. Staff

Academic staff are, in the main, extremely conservative. Teaching is also regarded by many of them as a 'private' activity. I have touched on many of the reasons for this lack of enthusiasm for change in earlier chapters. They stem from:

- the low status of teaching compared to research in many institutions, leading to;
- disproportionately few committed teachers among the senior (i.e. promoted) managers of most institutions and;
- the relatively higher cost (in both money and time) of any alternative to lecturing.

All these factors inhibit academic staff from devoting additional time to changing their teaching. In order to change the behaviour and attitudes of staff sufficiently, say, for them to take this book seriously, there are three preconditions:

1. Academic middle managers (Deans, Heads of School) must encourage change. They will probably only do this if their VC or Principal (University President in some other countries) is in favour;
2. Promotion must be possible on the primary basis of excellence in teaching. This need not necessarily be to the exclusion of research excellence;
3. Support and encouragement must be available from credible practitioner peers. Academics promoting change must feel part of a welcoming community.

The plural of 'anecdote' is not 'evidence', or even 'data'
Attributed to Lee Shulman (Carnegie Foundation)

In the UK the Higher Education Academy (HEA) is trying to address all these issues, but has not been helped by swingeing cuts in its funding from 2011. In particular, the Subject Centres of the HEA contribute substantially to the development of a strong community of engineering teachers.

Promotion (*item 2*) is a thorny issue which is why it was considered separately in *6.h above*.

The American Society for Engineering Education (ASEE) has produced a pair of reports (Jamieson and Lohmann, 2009, 2010) which address the difficult issue of how to effect change in (US) universities. The report strongly supports the themes developed in this book relating to experiential and active learning and the primacy of assessment, and it suggests ways of approaching the change of personal attitudes which is necessary before changes in these directions can be effective.

c. University systems

There are many ways in which 'legacy' university systems are ill-suited to support modern engineering education. While it has proved difficult to change many of these (not helped by conservatism from professional bodies involved in accreditation) a first step is to identify aspects of our current systems which do not match our educational aspirations. My own favourites are listed below, with comments, but I am sure that there are more. I expect my approaches to be, at the same time, both too radical to be acceptable and not radical enough to get it right! See what you think:

Exam pass mark: It is common for every element of a student's programme to have the same 'pass mark' – commonly 40%. This usually takes no account of the nature of the assessed item. In the context of engineering I would assert that some things have to be understood – for example the second law of thermodynamics is a central concept to much of engineering. Other topics may have a place in the curriculum for reasons of variety, or illustration, or as demonstrators of depth of understanding or as extension material, but are not essential for a graduate engineer. Surely it would be logical to make the 'pass mark' for essential concepts, competencies and skills 100%, while a lower value was acceptable for non-essential material?

Let's put it another way. How could you defend allowing a student to graduate who demonstrably does not understand 60% of the concepts which you regard as essential?

So why do most institutions not have elements of assessment with a simple pass/fail criterion (either you can do it or you can't) or a 90% pass mark (e.g. for a whole exam or parts within it) together with extension papers with a lower 'pass' mark to allow good students to demonstrate their wider and/or deeper ability? My question is largely rhetorical, but a real barrier to rational change is the ridiculous application of quasi-fairness and comparability within many institutions. No, it is not necessary, in order for the system to be fair, that every assessment item has the same pass mark. We just have to keep challenging the central imposition of unnecessary and indeed damaging uniformity.

Modules, credits and progression: It is now commonplace that our engineering programmes are broken down into modules which are separately assessed and the passing of which attracts 'credits'. The common currency is 120 credits per year of study giving 360 credits for a 3-year BEng programme and 480 for a 4-year MEng. The 120 UK credits map on to 60 European credits (ECTS), which are thus twice the size. Credits indicate the passing of the modules, not the level of achievement, which is separately totalled as a percentage. It is equally common to impose 'progression' rules based around the need to complete precisely 120 credits in a particular year before being allowed to enter the next year of study. It is also common that the possible credit values (i.e. size) of modules are constrained – perhaps they must be offered in multiples of 10 or 12 credits. A visitor from Mars would surely be puzzled by this very prescriptive approach. She would probably ask:

- Why do modules need to be the same size? Surely the whole programme has clear learning outcomes and achievement of these determines the degree outcome? What can it matter that the thermodynamics module is bigger or smaller than the introduction to control theory?;
- Why should a student be expected to collect <u>exactly</u> 120 credits before progression to a further year of study? Why does every year of study need to be identical? Surely the requirement for 360 or 480 credits can be met in a hundred different ways. Is not 105 + 125 + 130 as good as 120 + 120 + 120?;
- Why are we discussing 'progression' at all? It is true that some topics have a pseudo-linear development, and therefore it may be necessary to impose pre-requisites for the study of some advanced modules, but this has little to do with 'first year' and 'second year'.

I cannot justify these rules – versions of which exist at most UK universities – but I have found it difficult to persuade university administrators to agree to relax them. I suggest that you get yourself elected to your local Learning and Teaching Committee (at School Faculty or University level) and keep asking why things are done in ways which are less than ideal for the students and the quality of their eventual degree.

Synoptic assessment: A frequent criticism of modular education systems is that they encourage students to compartmentalise their knowledge and they discourage the formation of useful connections between different topics within a discipline. There is a very easy way to address this problem, and to encourage integrated or systems thinking. It is to set a 'synoptic' examination, that is a test which demands that the student draws knowledge from many topics which may have been taught in different modules, or may (horror) not have been explicitly taught at all. In some ways the final year project (whether 'capstone' or 'research') should encourage a synoptic view but in my opinion this is insufficient and the graduate would be better served by also sitting a formal examination. Most degree programmes of 30 years ago contained a 'general paper' comprising questions on wide-ranging topics but the rise of the modular system and the model answer, combined with the view that all students should undergo the same experience (presuming against choice of questions), has rendered the synoptic paper almost extinct. Why don't we re-establish it either as an oral exam (in a resource-rich world) or, more feasibly, as a general paper which carries credits but no teaching hours? The latter carries an apparent managerial bonus of 'efficiency gains' in that credits are awarded without the need for formal teaching.

Quality Assurance or Quality Enhancement processes: I have never heard an academic speak, even in jest, about wanting to lower the quality of the student experience. Anyone reading this book, and most of your friends, will want to do the best they can for their students, yet those funding universities feel the need to insist on a series of formal quality assurance measures. While quality enhancement (QE) is a more acceptable concept than quality assurance (QA) or – worse still – quality control (QC), I question the need for externally-imposed processes. It seems that these have been established (in the UK at least) in response to a number of perceived pressures. In essence these are:

- Audit – those who pay should know what is going on;
- Accountability – those who pay, whether government or student or both, should be able to ensure that they are getting value for money, and;
- Improvement – everyone involved should be trying continuously to improve the quality of higher education and thus graduates.

At first sight it is difficult to disagree with any of these motives. The problem is that externally imposed quality processes may not deliver the desired outcomes. The difficulties include:

- Measuring 'quality' – we have no clear, measurable, objective criteria for the quality of a graduate, nor of the educational process which leads to graduation;
- Response time – changes in higher education take many years to effect, not just because the 'committee cycle' is rather slow, but because the typical length of an undergraduate programme is four years. Even if we could measure it, it would take more than ten years to begin to evaluate the effectiveness of a change. For example we started to develop a major change in the engineering curriculum at Liverpool in 2002. This involved changes in the style of teaching and in the spaces we use to teach. The first undergraduates entered the new programmes in 2008 and will graduate in 2012. In about 2014 it

will start to be meaningful to ask them, and their employers, whether their degree programme was effective. So for 12 years we have had to operate on a hunch that we are making an improvement. This is about two or three times longer than the tenure of a government, a Head of School, a Vice-Chancellor or a typical educational initiative!;
- Cost – all mechanisms put in place to enhance quality have costs associated with them. These costs include directly identifiable elements (e.g. the running cost of the QAA or its successors) and indirect opportunity costs such as the time of the staff who are being audited or inspected. It has for many years struck me as ironic that every time my School was audited or inspected, I and other colleagues had to cancel or postpone teaching commitments. This does not appear to the students to be quality enhancement.

Do not imagine from the paragraphs above that I do not care about quality. I and most of my colleagues care passionately about the quality of our teaching and the students' learning. I expect and hope that you do too. However the best way of ensuring and enhancing that quality is from within, with senior members of the university demanding that staff take teaching seriously. The only driver which matters is the student (and eventually graduate). In the long term any institution which does not pay attention to the quality of its teaching will suffer a loss of students and hence income, and this will threaten the viability of the institution. That's the only driver a VC needs.

Accreditation: Many engineering programmes are accredited by one or more of the professional bodies on behalf of the Engineering Council (or ABET in the USA, CEAB in Canada or Engineers Australia in Australia). There are many positive aspects of this arrangement, including the knowledge which professional bodies gain about education and graduates, and strengthened interaction between academe and industry. It may also provide a School with external evidence for the excellence of its programmes, for use internally (for instance in budget discussions). However most of the criticisms of QE processes listed above also apply to accreditation. I am not convinced that the balance of advantage is in favour of either the student or the profession (or even society at large). There are many reasons for this view, but three of the principal are:

1. The pace of change in future is likely to be faster than the time constant for accreditation;
2. Accreditation has little effect on the quality of engineering practice, which can only be controlled by engineering contractors, supported or hindered by government regulation;
3. New types of engineering (eg inter-disciplinary) are likely to emerge faster than accreditation can keep up.

Nevertheless I would encourage you to involve yourself in the accreditation activity of your professional body. It is important that practicing teachers are well represented in the accreditation process, which will otherwise be dominated by retired ex-practitioners.

External examining: The external examiner system is almost unique to the UK and is widely regarded as encouraging, if not guaranteeing, comparability of standards across the UK's institutions. In the later decades of the twentieth century an external examiner was expected to act as an additional examiner, reading samples of work and either confirming marks or recommending changes. She would usually interview students whose marks placed them on the borderlines between degree classes, and her verdict would usually be accepted without question. (Not entirely surprisingly – this absolved staff from making difficult decisions for themselves!)

More recently the role of external examiner has come under scrutiny and has evolved quite considerably. Modern ideas of equality and fairness have led QE authorities to frown upon the interviewing of individual students, and certainly upon the hitherto normal practice of interviewing only selected students. The reliability of an external examiner adjudicating on marks based on a cursory exposure to the material has also been called into question. As a result the role of the external examiner has been more tightly defined. She usually reports directly to the Vice-Chancellor or Principal on the appropriateness of the learning outcomes, the level of the taught material and on the examination process. External examiners are now explicitly discouraged from commenting on the performance of individual students.

This new way of working maintains the traditional view of the external examiner as a 'critical friend' but implicitly the word 'examiner' now applies to the School and not to the students. An experienced examiner can still comment on, and influence, the standard of the degree award and its comparability across the sector but cannot be used as a referee or adjudicator.

I believe that this system still delivers benefits both to the School and to the examiner. It ensures that good practice in one institution is seen (and can be adopted) by staff from another. It allows senior staff in the host university to be alerted to falling standards or unfair practices. However it relies on a level of educational understanding and expertise in the examiner which probably makes a training/briefing session necessary. Some universities do this for all their external examiners; Others as yet do not. Either way external examining is a responsible and significant role, rarely rewarded with a fee commensurate with the effort required but worth doing because of what you, the examiner, learn. I would encourage you to get involved, initially just by mentioning your interest in acting as an external examiner around your profession network of colleagues in other universities.

Finally, I will list a few of the questions which it would be proper to ask while acting as an external examiner (several of which are touched on elsewhere in his book):

- How do you assess the learning outcomes given in this module specification?;
- Where do you assess deep learning?;
- Where and how do you assess creativity?;
- Why is the pass mark x%?;
- Why do you allow a choice of questions in written exams?;
- Do you scale marks and if so why?;
- How do you assess individual contributions to team work?;
- How do you eliminate the influence of the supervisor when assessing student project work?;
- Have you detected any plagiarism? What do you do about it?;
- What is the process and timescale by which my comments will taken account of?;
- And of course: Have you read Peter Goodhew's book?

What you might take away from this chapter:

- Students can be persuaded to behave in educationally useful ways if you expect this of them at an early stage;
- Staff need encouragement from middle and senior management to give serious thought to teaching;
- There are many examples of University systems which are not best fitted to deliver top-class engineering graduates. Changing these is probably the hardest task of all, but should be attempted.

A class using 'clickers' © eInstruction

Chapter 8: The way forward

a. The next few years

It requires no great insight to conclude that higher education, in the UK and to some extent elsewhere in the world, is going to suffer funding problems over the next 5 years (2010 to 2015 as I write). Despite this constraint it seems likely to me that there will be an increase in active learning, an increase is the number of academics prepared to take teaching very seriously and an increasing influence of non-traditional disciplines on engineering. I have in mind biology, psychology (human factors) and planning but I am sure there will be others. The techniques and issues discussed in this book will continue to be debated and practice will gradually (but not rapidly) change. I am not the only elderly academic to believe that we have now reached the tipping point beyond which it will become increasingly acceptable for an academic to concern himself seriously about learning and teaching.

b. The next 50 years

In this final section I want to peer further ahead, and raise some even bigger questions about where engineering education is going. Clearly neither I, nor anybody, can be certain that any of my predictions will come true, but I would bet that several of them will. However I make no claims for this very speculative section!
First let me make some not-very-clever assertions, which I regard as very likely to come to pass:

- In future, graduate working lifetimes are likely to be >50 years;
- There will be regular national and international crises. There will be a number of ‘grand challenges’ (global warming, energy, water…);
- There will be rapid change in ways we cannot today imagine. The rate of change will be higher (Moore’s law for engineering?);
- The macroscopic laws of physics will not change;
- There will be more ‘knowledge‘;
- Information will be readily accessible, by almost anyone, almost anywhere;
- There will be new engineering disciplines;
- Biology will be more important, and more controlled;
- Engineers, and understanding, will be even more crucial to the operation of society;

If you believe most of this, a number of consequences follow:

We will have to design and offer engineering courses, now, which can provide the basis for practise as an engineer in 55 years time. To give you a feel for the engineering advances likely in this long period of time I will list some of the familiar things we take for granted in 2010 which had not been invented, discovered or accepted 55 years ago, when I was a schoolboy. In no particular order: Laser, PC, mobile phone, optical storage, internet, heart transplant, MRI, space travel, pulsar, catalytic converter, fuel injection, CCD, digital imaging, jet airliners, photocopier, geodesic dome, bucky ball, VCR, integrated circuit, LED, LCD, genetic modification, spreadsheet, cheap air travel, the Euro, security scanners and nuclear power. We have no chance of predicting what the equivalent list will look like in 2065 and therefore there is no point in trying to tailor engineering education to meet it. Indeed the strongest argument could be made for concentrating on physical fundamentals to the complete exclusion of applications. What we have learned by experience is that this is unlikely to motive a sufficient number of students, so I doubt whether this will happen.

I will make a few more, less certain, assertions:

- Few individuals will be prepared to spend more than 4-5 years on their initial formation as an engineer;
- The apparently most important applications for engineering (in terms of addressing society's issues) will change every ten years or so;
- Bio-inspired processes will become important to engineers;
- We cannot, and will not be able to, demand depth of study in all areas deemed 'important' by any group of engineers or employers (or even academics!).

Since I cannot predict what engineering content we might need in future, let's zoom out to some generalities. What might be the future purpose of engineering education? What are our graduate engineers to do? It is likely to be more than one of the following list:

- Creative innovation (… design new things);
- Entrepreneurial activity (… make money);
- Research (… expand our knowledge);
- Work as engineers in wealth-creating industry (… keep the economy going);
- Work as non-engineers (… keep society going);
- Vote (… encourage states to do the right thing);
- Continue to learn (… or get left behind).

A key question for future educators is therefore how many of these purposes can be addressed in a single higher education system? How many of them should be taken into account when devising a single engineering programme?

A related question is how we should partition the available learning time (say four years of initial formation) between:

- Expertise and knowhow (… can do);
- Knowledge (... understands);
- Appreciation (… is aware of);
- Communication skills (… can explain);
- Societal understanding (… does the right thing).

In thinking about the attributes of the future engineering graduate, I like to address the question via assessment. What should we test after 4 years? I suggest:

- The ability to hold a discussion with an expert about one topic at the cutting edge of research (demonstrating ability to study in depth);
- The ability to formulate a reasonable solution to an open-ended engineering problem given incomplete data (demonstrating engineering aptitude);
- The ability to tell a story, and answer questions, about the development of an engineered artefact – to include all aspects of its life cycle from societal need to eventual disposal (demonstrating understanding, societal and communication skills);
- The ability to retrieve information and deploy it quickly and accurately (demonstrating knowledge, agility, dynamism, persistence);
- Credibility as a team member, and possibly as a leader (demonstrating employability).

It seems to me that, perhaps with the exception of the fourth, none of these attributes is best tested using a conventional written examination. If anything needs to change over the next 50 years, it is our methods of, and motives for, assessment.

I realise that I have posed a large number of questions and given almost no answers, but this is the nature of the future – none of us knows what it holds, which is why it is so fascinating. Do enjoy it.

What you might take away from this chapter:

- Engineering education is unlikely to be static;
- We cannot predict what we might need to teach, but we can ask ourselves what generic attributes we want to inculcate;
- We could perhaps start by looking at how, why and what we assess.

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Appendix 1: Where to find resources to support your teaching

CORE-Materials	http://core.materials.ac.uk
ENG-OER Open Educational Resources site	http://www.engsc.ac.uk/oer
Pearson: Mastering Engineering	www.masteringengineering.com/
DrFrame2D (Truss bridge design)	http://www.drsoftware-home.com/
West Point Bridge Design software	http://bridgecontest.usma.edu/
MIT Open Courseware	http://ocw.mit.edu/
Open University OpenLearn	http://openlearn.open.ac.uk/
Jorum Open	http://open.jorum.ac.uk
Enhancing Diversity in the Undergraduate Mechanical Engineering Population through Curriculum Change	http://www.engineeringexamples.org
Racing Academy	http://www.jisc.ac.uk/whatwedo/programmes/elearninginnovation/racing.aspx
ReSET: Rejuvenation of Science Engineering and Technology related TLTP and other legacy material (mostly Elec Eng, Maths and Materials Science)	http://www.icbl.hw.ac.uk/reset/index.htm
iTunes U	iTunes

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About the Author

Peter Goodhew is an Emeritus Professor in the School of Engineering at The University of Liverpool. He has worked at the University of Surrey, Cornell University and The University of Liverpool. At various times he has served as Head of Department, Dean of Engineering and Pro-Vice-Chancellor at Liverpool, and is a Fellow of The Royal Academy of Engineering. His interest in undergraduate education developed gradually over the 40 years of his career, eventually growing to engage far more of his attention than his technical specialism, electron microscopy. He now cannot remember when his self-description changed from electron microscopist (which no-one could pronounce) to engineering educator (which no-one could understand). Along this thoroughly enjoyable path, Peter established a team who write educational software (MATTER – see www.matter.org.uk) and led the UK Centre for Materials Education (UKCME – www.materials.ac.uk) through its first decade. This is his first book about education, following half a dozen similarly short volumes on electron microscopy. As his dotage approaches Peter keeps on writing, turns unnecessary wooden articles on his lathe, and worries about the future of education in the UK (and also the future of his grandchildren).

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