Teaching Materials Engineering
an updated guide

2nd edition
Edited and updated by Peter J Goodhew
Preface

In 2003 the UK Centre for Materials Education published a series of booklets entitled ‘Guides for Lecturers’. Since then the annual workshop for new lecturers in Materials, based partly on the content of the Guides, has become an established feature of the teaching calendar. In 2010 I wrote a more general text entitled ‘Teaching Engineering’. It now seems timely to update the Guides and publish them as a single supplement to ‘Teaching Engineering’, containing ideas and examples specific to Materials Science and Engineering. In order to make each section readable on its own, and to preserve some of the idiosyncrasies of the original authors, I have unashamedly re-used much of the text from many of the original guides. Although this has resulted in some inconsistency of style, I hope it helps the reader more than it irritates!

I must give full credit to the original authors, who are listed below.


I have frequently changed the original first person singular (I) to first person plural (we). In doing so ‘we’ indicates that I share the blame for mistakes or inadequacies with the original authors!

All of the 2003 Guides and most of the documents and reports mentioned in this updated guide are available on the UKCME web site [www.materials.ac.uk] and also in CORE-Materials [www.core.materials.ac.uk].

Peter Goodhew, August 2011
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Introduction

The text is arranged in an attempt to address, in five parts:

1. What to teach;
2. How you might teach it;
3. How to assess the students’ learning;
4. How to evaluate your own success; and
5. Some case studies and generic templates.

We have done this on the clear understanding that Materials is taught in several contexts. A minority of teaching is delivered within a Materials Department or School, to undergraduate programmes with ‘Materials’ in their title. A larger proportion of teaching is within Departments or Schools of Engineering, where Materials features as a minor but important subject – often loosely called ‘Materials for Engineers’. A further tranche of teaching occurs within a wider range of disciplines where there is a special need for an understanding of Materials, but this is often not recognised as being central (although perhaps it ought to be!). Among these disciplines are Art & Design, Dentistry, Medicine, Architecture, Earth Sciences, Physics and Chemistry.

Benchmarks for the teaching of Materials

In the UK, you might expect the QAA Benchmark statements and the Engineering Council’s UK-SPEC to give some guidance on the Materials content and appropriate topics for this variety of teaching contexts, but you would be largely disappointed.

Materials programmes in the UK all take note of the QAA Benchmark statement for Materials [www.qaa.ac.uk/Publications/InformationAndGuidance/Documents/Materials08.pdf]. It is a permissive rather than a prescriptive document and some of its key content guidance is extracted in the table below. We believe that all significant programmes conform to it, although this results in some quite diverse programmes with very different emphases.

We have extracted all the (rather scarce) mentions of Materials from other Benchmark Statements – and UK-SPEC – and put them alongside some of the content statements from the Materials statement for comparison and to inform staff delivering Materials content in non-Materials programmes. Many of the statements are
very general and cannot be specifically related to the Materials Statement.

Astonishingly the Engineering Benchmark Statement [www.qaa.ac.uk/Publications/InformationAndGuidance/Documents/Engineering10.pdf] makes not a single reference to the materials from which all engineering products are made. It makes no reference to curriculum content and defers to the UK-SPEC [www.engc.org.uk/professional-qualifications/standards/uk-spec] on this key issue. UK-SPEC itself has only a single reference to Materials in the context of the lowest level (Eng Tech). However, some of the individual accrediting institutions do mention Materials in their own supporting documentation.

‘Since matter is everything that can be touched, seen, smelt or felt, it follows that the scope of the Chemistry discipline is essentially limitless’. We love this sentence from the Chemistry Benchmark, but for Chemistry we should surely substitute Materials Science!

<table>
<thead>
<tr>
<th>A brief summary of Materials in Benchmark Statements</th>
<th>Other Disciplines</th>
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<tbody>
<tr>
<td><strong>Materials Science and Engineering</strong></td>
<td><strong>Chemistry</strong>: students gain knowledge of a range of inorganic and organic materials and skills in the safe handling of chemical materials.</td>
</tr>
<tr>
<td>It is anticipated that materials graduates will have an awareness of a range of materials, and some familiarity with relevant concepts associated with most of the following:</td>
<td><strong>Earth Sciences</strong>: the chemistry, physics, biology and mathematics that underpin our understanding of earth structure, materials and processes. The study of structures, materials and processes ranging in scale from atoms to planets.</td>
</tr>
<tr>
<td><strong>structure of materials</strong>: electronic, atomic, bonding, crystalline, amorphous and multi-phase; and structure on the nano, micro, meso and macro-scales.</td>
<td>Degree programmes in <strong>earth sciences</strong> will encompass studies of the structure and composition of the solid earth, and the processes operating within and between them, and</td>
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| **phase equilibria and phase transformations**: thermodynamic and kinetic aspects. | }
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<table>
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<tr>
<th>and X-ray diffraction; scanning probe techniques; thermal analysis; and some aspects of traditional chemical analysis.</th>
<th>issues concerning the availability and sustainability of resources. Graduates should have the ability to describe and record materials in the field and laboratory.</th>
</tr>
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<tr>
<td><strong>mechanical behaviour:</strong> elastic and plastic deformation and fracture, for example, creep and fatigue; strengthening, toughening and stiffening mechanisms; mechanical test methods; and continuum mechanics.</td>
<td><strong>Analytical Chemistry</strong> is concerned with the identification of materials and the determination of composition.</td>
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<td><strong>functional behaviour:</strong> semi, dielectric and optical conducting; and magnetic materials.</td>
<td><strong>Biomedical Science:</strong> a biomedical science graduate will have a knowledge of microscopy and its applications.</td>
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<td><strong>biomaterials:</strong> materials that interact with biological systems; materials of biological origin; and biomimetics.</td>
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<tr>
<td><strong>processing and manufacture:</strong> processing and synthesis of materials via gaseous, liquid, colloidal, powder, solid state and deposition techniques; joining and fabrication methods; surface treatment; heat and mass transfer; and fluid mechanics.</td>
<td><strong>Art and Design:</strong> students learn to recognise the interactive relationship between materials, media and processes.</td>
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<tr>
<td><strong>degradation/durability of materials:</strong> effect of liquid and gaseous environments on the performance of different material types; wear of materials; and biodegradation.</td>
<td>On graduating with an honours degree in <strong>art and design</strong>, students should be able to develop ideas through to outcomes that confirm the student's ability to select and use materials, processes and environments.</td>
</tr>
<tr>
<td><strong>materials selection:</strong> consideration of all material types, including material processing methods, and product costs; selection criteria for materials and production processes.</td>
<td><strong>Dentistry:</strong> students should use their knowledge of the properties of modern dental materials to select and use appropriate materials for treatment; graduates should be able to restore teeth to</td>
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design with materials: this area is key to the use of materials. Graduates in materials should have the ability to select appropriate compositions and use processing to achieve the required microstructure, hence the required structural and functional properties in a product, often in order to meet specifications.

lifecycle analysis, sustainability and environmental impact interaction and application: interaction between composition, processing, microstructure and properties, leading to appropriate application of materials.

Materials graduates should have had opportunities, through practical work, for first-hand experience of a range of techniques and materials (artefact analysis, characterisation, processing, testing etc) designed to develop the ability to plan, implement and interpret experimental investigations. Experience of computer modelling techniques is also desirable.

You should also consult:

- The National Subject Profile for higher education programmes in Materials, which gives a great snapshot of what and how universities in the UK are teaching, and the nature of their students and staff. [http://www.materials.ac.uk/subject-profile/report.asp].
The UKCME overview of UK Materials programmes and the National Student Survey (NSS) [http://www.materials.ac.uk/pub/nss2010.asp] which gives some (partial) information on how students view our programmes.
Part 1: What to teach

This section reflects the original emphasis of the Guide series, which contained four titles on Chemistry, Environmental Materials, Materials for Engineers and Professional Skills. We have integrated these into this, ‘What to Teach’ section with, obviously, no claim to be offering comprehensive coverage of the whole of Materials Science!

Underpinning Science

You probably have a good idea of the core Materials content which your whole programme, or your contributing module, is intended to deliver. It may have a specific material flavour – metals, polymers, ceramics, composite materials, opto-electronic materials – or it might be very general ‘Materials Science and Engineering’, or it might be process-based like ‘Materials for Manufacturing’. Most of this material has the advantage (to the teacher) of being new to most students. You can therefore devise the module or modules with few constraints, using your own expert knowledge. The more difficult task is to assess, and then remedy, the absence of key knowledge from the science disciplines which are likely to have been studied prior to entry to university. Entrants to UK Materials programmes are heterogeneous and diversely qualified, with (in 2006) fewer than half having an A-level in Chemistry and only 18% having passed all three of Maths, Physics and Chemistry [http://www.materials.ac.uk/subject-profile/report.asp]. Entrants to, say, Mechanical Engineering might be less diverse but more likely to lack – especially – Chemistry.

This diversity of background knowledge makes it difficult to design appropriate Materials modules for any programme. It is perhaps Chemistry which poses the greatest problem, which is why a booklet on this subject was originally commissioned. In response to this we want to make two suggestions:

1. It would probably be worth the effort to deliberately evaluate the chemical understanding and experience of your in-coming students. You could do this with a class test of your own devising, or you could use the Engineering-Transition questionnaire at www.stem-transition.ac.uk, which was produced to assess areas of knowledge and ignorance of students arriving for their first year of an undergraduate programme in Engineering.
2. You need to construct a list of the key chemical concepts which will be important in your programme. To start this process we offer our own list, which may be too long for your needs but from which you can select:

- The periodic table, electrons, atoms, ions, radicals;
- Bonding between atoms, molecules, compounds and metals;
- Reactivity (as an introduction to chemical potential);
- Carbon-chain polymers;
- The balancing of a chemical reaction equation;
- The idea of phases (at least gas, liquid and solid);
- First and second laws of thermodynamics;
- The ubiquity of crystallinity;
- The carbon cycle;
- Photosynthesis;
- Some bio vocabulary (e.g. ‘protein’).

You can argue whether some of these are ‘chemistry’ but it does not really matter what you call them – they are going to be important over the 50-plus year working life of our graduates.

A further suggestion is that you might illustrate some of the important bonding and molecular ideas using one of the increasingly-available chemical visualisation tools. A favourite of mine is ChemTube3D, created and maintained by Nick Greeves at http://www.chemtube3d.com/.

You might need to consider whether to adopt a similar approach to your students’ understanding of Physics and Mathematics. The issues surrounding first-year mathematics are long-standing and many universities have evolved ways of addressing this problem, so we will not consider it further here. There are many questions on basic physics in the Engineering-Transition questionnaire cited above.

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Materials for Engineers

The development of a syllabus for a module (or two) on ‘Materials for Engineers’ is challenging. Mike Bramhall’s analysis [http://www.materials.ac.uk/guides/engineers.asp] starts from the point that Materials is often seen as a subsidiary subject by engineers. Only when materials failure occurs does the importance of materials selection become apparent. It is therefore important when teaching engineering students that they accept the value of the Materials Science element of the course. Materials has its foundations in physics and chemistry and is regarded by many Materials academics as a science. It therefore tends to be taught with an emphasis on ‘why?’ rather than ‘how?’ Engineers may regard the subject in a more practical sense and may wish to know about engineering properties, rather than the science that explains why materials behave as they do. The engineer’s focus on applications places value on materials selection over materials science theory. Selection by software programs limits the engineer’s feel for the material (e.g. for aesthetic purposes) and this may constrain innovation. It is therefore important when teaching engineering students that they are taught some of the underpinning science, whilst also being given the opportunity to gain a feel for materials through practical sessions, perhaps by mechanically testing materials to determine properties.

What does the mechanical or design engineer or technologist actually need to know about materials? What key aspects might be covered in a first year module in Materials?

The following gives a possible overview of what could be included in a first year curriculum:

- Materials selection;
- Polymers;
- Composites;
- Ceramics;
- Metals;
- Electrical properties;
- Mechanical properties;
- Degradation and corrosion;
- Shaping processes;
- Casting and solidification;
- Deformation of Materials;
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- Heat treatment;
- Phase diagrams;
- Crystal structure;
- Atomic structure and bonding.

In the first year, engineering students need to be taught the underlying fundamental principles of materials. They also need to find out about the different types of materials available, with some idea of how to choose among them for specific applications. This implies quite a full syllabus if it is to be done effectively. However, some academics are under pressure to reduce teaching hours and hence have reduced contact time with students. In some cases the amount of taught material must therefore be reduced. If this is the case, we need to consider what the minimum requirements are in terms of topics to be taught. So what topics do we really need to have in the curriculum? Do we need for example all of the following?

- Periodic table;
- Electronic structure of materials;
- Crystal structure;
- Dislocation theory;
- Phase diagrams;
- Microstructure.

Despite its inclusion in the list of chemistry topics above, is it really necessary for the Periodic Table to be dealt with in detail, or would an overview suffice? Some think that topics such as atomic bonding and diffusion within crystals should not be taught to an engineer, as they don’t need to know this to select a material for an application. However, it could be argued that an understanding of these topics is fundamental to understanding ‘why’ we choose (or deliberately do not choose) a certain material; or ‘why’ we choose a certain process to treat or fabricate a material. A knowledge of structure and bonding also leads to a better understanding of the properties of materials and how and why they can be changed by processing.

The alternative approach, advocated by many academics, is to present all materials in the context of what is needed for a product (bicycle, iPad, or whatever). This can be done using CES [www.grantadesign.com] for example. The scientific basis is then only introduced when necessary to explain behaviour.
Let us look at one approach to topics taught in a first year class for Engineers over one semester.

<table>
<thead>
<tr>
<th>Week</th>
<th>Lecture (1 hour)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Materials classification / Periodic table / Bonding</td>
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<tr>
<td>2</td>
<td>Crystal structure of metals – FCC/BCC/CPH</td>
</tr>
<tr>
<td>3</td>
<td>Solidification / Grain structure and defects</td>
</tr>
<tr>
<td>4</td>
<td>Principles of Alloying</td>
</tr>
<tr>
<td>5</td>
<td>Stress-strain / tensile testing / hardness tests</td>
</tr>
<tr>
<td>6</td>
<td>Steel and its heat treatment</td>
</tr>
<tr>
<td>7</td>
<td>Copper alloys, microstructure and properties</td>
</tr>
<tr>
<td>8</td>
<td>Polymers, classification, structure and properties</td>
</tr>
<tr>
<td>9</td>
<td>Composites, types and properties</td>
</tr>
<tr>
<td>10</td>
<td>Ceramics, classification, structure and properties</td>
</tr>
<tr>
<td>11</td>
<td>Toughness and fracture</td>
</tr>
<tr>
<td>12</td>
<td>Creep and fatigue</td>
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</table>

This lecture programme would also be supported by appropriate laboratories and tutorials. Other topics that are included in the first year curriculum overview could replace some of the above topics, or could be taught through student case studies and assignments associated with the module. Examples of case studies are given in Part 5. You may decide to put some topics into a second year or final year module.

**Improving the teaching of Materials to Engineering students**

Students need to have the fundamentals of Materials in place very early on. Having decided on the main topics that you wish to cover, one potential problem is that the students aren’t really interested in Materials, as it is not a core topic for their award. So, how do we ensure that our Engineering students generate an intrinsic interest and motivation in studying Materials? There are several points that we need to consider to address this. We need to:

- Review the Materials content of the course;
- Appreciate where the first year student is ‘at’;
- Adjust to their diverse intellectual levels;
- Think about the relevance of the Materials topics being taught;
- Think about how we can generate interest and motivation within the student.

There are some ideas about tackling these difficult issues in the parent book ‘Teaching Engineering’.
Environmental Materials

Cris Arnold’s original booklet [http://www.materials.ac.uk/guides/environmental.asp] set the scene in the following way:

Issues of environmental protection and sustainable development are gaining importance in everyday life, and nowhere is this more so than in the field of Materials Science and Engineering. Almost every aspect of materials usage, from extraction and production, through product design and ultimately disposal, is now subject to environmental considerations. Furthermore there are many cases where the development of novel ‘environmentally-friendly’ materials is providing new challenges for Materials Scientists and Engineers.

The growing awareness of environmental issues has increased the attention focused on the materials industry. There is a danger that this could give a negative picture, highlighting examples where materials production and use has led to environmental problems. In many of these cases, materials, additives and production methods were used for very good materials engineering reasons before environmental concerns were established. The more positive image of materials engineering that can be portrayed is one where the industry is at the forefront of technical advances – not only to ‘deal with past mistakes’, but also to drive sustainable and safe use of materials for the future.

The topic of ‘Environmental Materials’ is broad and can touch on some quite deep aspects of materials structure, chemical and physical properties, processing and design, as well as more general areas such as legislative, economic and social aspects. Interesting topics within this area can be presented at a range of levels: for instance the sustainable use of materials in the IT sector can be discussed by 11 year olds with as much enthusiasm as by post-graduate students – although the latter would be expected to grasp the chemical details of identifying brominated flame-retardants, whereas the former would consider much simpler aspects, that are nonetheless important.

Here we provide information on what can be taught under the broad title of Environmental Materials; how it can be most effectively delivered to students; and how it might be assessed. The next section gives details of the subject areas that should be covered within this theme and provides some suggestions about
how these different areas can be linked together. Effective teaching and assessment methods are then discussed, reflecting the fact that as this subject is a rapidly-changing one, there is perhaps less reliance on factual information and a greater need to encourage individual interpretation of more subjective information. The examples in Part 5 contain two case studies which show how these ideas can be put into practice.

**Topics which might be taught, all of which relate to sustainability**

Life Cycle Analysis (LCA) is essentially a method of considering the entire environmental impact, energy and resource usage of a material or product. It is often known as a ‘cradle-to-grave’ analysis and can encompass the entire lifetime from extraction to end-of-life disposal. Life cycle analysis can be an extremely effective way of linking many different aspects of the environmental impacts of materials usage. The scope of a life cycle analysis can be adjusted to suit a particular case. For instance it could cover the environmental impact of the global aluminium industry or simply that of one single plastic injection moulding machine. In order to gain most learning benefit from this area, students would be expected to have a good grasp of the necessary underlying technical areas, which could be quite complex and so this ideally suits more advanced degree level students. The most conventional way of approaching a life cycle analysis is to follow a particular material or product through its lifetime. Therefore the first consideration would be the impact of materials extraction, and then production and manufacture, product use and finally end-of-life considerations. This approach is followed below. Various aspects, such as energy usage, economic and legislative issues occur through the cycle.

The most recent versions of the Cambridge Engineering Selector Edupack include many environmental and energy data about a very wide range of materials. This can be a very valuable resource for both teacher and student.

Materials extraction, resource implications, environmental impacts, sustainability and ‘green’ energy and materials are all aspects of the current approach to the Brundtland principle of development which ‘meets the needs of the present without compromising the ability of future generations to meet their own needs.’ [http://www.un.org/documents/ga/res/42/ares42-187.htm]: (United
The environmental impact of raw materials extraction and processing together with global resource issues provides a good place to start the consideration of environmental aspects of materials. Indeed taking this approach can provide a more interesting way of dealing with subjects such as extraction metallurgy that can otherwise come across as very dry and factual. This can be taken at quite a basic level covering materials abundance and the energy required for extraction, up to a detailed consideration of environmental impacts of extraction processes. For example, the production of aluminium requires large amounts of energy and produces a significant contribution to overall greenhouse gas emission. By comparing energy usage for extraction of new aluminium, students will see the large benefit to recycling in this case. Similar arguments apply to much processing technology.

The design, production and use of ‘sustainable materials’ are at the heart of this subject, and yet the definition of such a material is hard to specify. It could easily be argued that steel is a very sustainable material; it is abundant, takes relatively little energy to extract and is easy to recycle. However people living near a steelworks would probably argue against this. It is probably sensible to define sustainable materials as those that have distinct differences that achieve environmental benefit compared to conventional materials. With this definition, the list would include:

1. Materials of a significantly plant-based nature, including wood, natural fibre composites, natural polymers;
2. Materials produced using a large proportion of waste material, including recycled polymers, composites made from waste mineral powders, and arguably also much steel and aluminium.

Some of the most exciting developments in Materials Science are in the realm of functional materials, and many of these serve an environmentally-beneficial purpose, particularly in the production of green energy. These include:
Solar-cell materials;
Fuel-cell technology;
Catalytic pollution control.

Finally, the treatment of materials at the end of their lifetime is a significant subject area; and encompasses aspects such as recycling techniques and materials limitations, biodegradability and composting, chemical recovery and energy recovery.

A case study involving the incorporation of materials into a sustainability module is described below and included in Part 5.

**Teaching issues**

For students to gain maximum learning outcomes from this area they need a certain amount of basic knowledge. This includes:

- Details of environmental legislation and economic factors. Although these topics take us beyond the normal realm of a Materials specialist, there are many important aspects that have a significant influence on the more technical issues. For example, materials selection within the automotive industry is now heavily influenced by ‘end-of-vehicle-life’ and ‘hazardous material’ regulations;
- Processing methods, especially their energy requirements;
- Materials composition, structure and behaviour;
- Details of environmental impacts (e.g. the detailed chemical mechanism by which CFCs deplete the ozone layer).

The methods by which students obtain this information can vary, depending on the level of initiative expected from the students. It could be presented via conventional lectures, with supporting multimedia material. If students are given more time and responsibility for their learning, they could be required to undertake a literature/information survey. However, with this method it is quite common for important information to be missed or not understood.

The area of environmental materials presents an exceptionally good opportunity for other teaching and learning methods that are much more suited to the quite subjective and rapidly changing nature of the subject such as:

- Group discussion;
One example where group discussion has proved to be an effective learning tool is the consideration of new environmental legislation. Once students have become familiar with regulations dealing with packaging, automotive and electrical sectors, they could be asked to consider what should be in legislation aimed at other sectors, for example construction and agriculture.

Self-directed information reviews are used most effectively to gather factual information and details of new materials/technologies being used to address environmental concerns. An example might be for students to collect information on how the major automotive companies are planning to deal with forthcoming end-of-life vehicle regulations.

Market research is an interesting way for students to gain information on more subjective issues such as public perceptions, marketability of products and so on. In project work, there is scope for students to undertake surveys via questionnaires or door to door surveys.

Case studies can be used to bring many important aspects together. For instance, an interesting case study might be to consider the environmental impact of PVC use. In order to do this effectively, students would need to have access to factual information on PVC production methods, additive technology including plasticiser chemistry, recycling methods, dioxin chemistry and the associated health risks. With this information, students could then consider the more subjective issues of the overall environmental risks posed by PVC, the optimum disposal routes and the benefits of long outdoor lifetimes when replacing other materials that required paint or preservative treatments.

The significant learning objective in such a case would be the consideration of the full lifetime environmental impact in order to make reasoned comparisons with alternative materials. For students to be able to do this, a distinction must be made between the factual information presented, about which there is little argument, and the subjective issues, where students should be encouraged to take a range of standpoints and argue their
advantages/disadvantages. Two further case studies are detailed in Part 5.

All the first-year students in Engineering at the University of Liverpool have for the last 7 years received teaching in Design for Sustainable Development through an individual written assignment. Richard Dodds, a Royal Academy of Engineering Visiting Professor at Liverpool, comments that although serving its purpose well in meeting accreditation requirements, the objective of introducing students to the various economic, social, environmental and regulatory aspects of Sustainable Development resulted in assignments whose contents, on average, were very light technically.

Each assignment required the student to suggest and justify the choice of more sustainable design for a component of their choice – typically an aircraft wing, a bicycle frame or a battery. An opportunity arose to reinforce the materials aspect of the assignment in the 2010-11 academic year for one class of 250 Mechanical, Civil and Aeronautical Engineers (Class 1) and later a class of 60 Electrical and Electronic Engineers (Class 2). This shows promise but, as the following comments indicate, is not straightforward:

Class 1

This class were asked to consider qualitative materials property aspects from the outset of the assignment, homing in on materials aspects in their implementation approach at the final stage of the assignment. Whereas the best students did a first-rate job, the introduction of even qualitative materials aspects early in the assignment, simultaneously with the need to grasp the broader sustainable development framework, was clearly too much for the average student.

Class 2

This class were asked to consider materials aspects only at the later implementation stage of their assignment. The average student managed this better, but the materials aspects were still not integrated coherently.

In order for each class to be aware of the expectations, a demonstration assignment will be prepared, probably in the area of light-weighting of vehicles for Class 1 and an electronically oriented
example for Class 2. The opening lectures will cover the demonstration example in detail and then the students will be asked to select their own product for analysis as usual.

One of the better student responses is shown (anonymously) among the Example Case Studies as C11.
Professional Skills

The original booklet by John Wilcox [http://www.materials.ac.uk/guides/developing.asp] had two principal objectives: the first was to highlight the skills required for successful, lifelong professional development. These skills, like many others in life, can only be acquired by coaching and by practice. The second objective was to suggest strategies and methodologies which can assist in the acquisition of professional development skills. The original emphasis was on the development of Materials graduates in employment, but professional skills are nowadays seen to be so important that their development is encouraged within undergraduate programmes. The text of this section has therefore been modified to reflect this approach.

For many people in further and higher education, professional development is synonymous with short courses or with post-graduate qualifications. However, professional development is more than training or continuing education; increasingly it is recognised that learning also occurs in the workplace, as an integral part of working. Work-based learning focuses on solving real world problems. The time and effort invested in the learning are immediately rewarded through completing the task in hand and the usefulness of such learning, together with the short-term nature of the rewards, improves the motivation to learn.

Professional development therefore covers a wide range of learning situations:

- Private study and reading;
- Attending conferences and seminars;
- Preparing papers and presentations;
- Committee work;
- Collaborative work with colleagues;
- Conversation and discussions with others;
- Courses and distance learning;
- Researching the solution to problems;
- Working with others outside the organisation.

To these we might add the learning and development that take place when we are transferred to new situations, or when we take on new responsibilities within our existing job functions. Professional development also includes the full range of intellectual
discipline, from conceptual understanding to the practical application of knowledge.

The informal and ad-hoc nature of much professional development poses problems for us as educators. How do we evaluate and assess it? How can we recognise and reward it?

Professional development is not a new concept, but it is becoming increasingly important. The continuing pace of change in Materials Science and Engineering means that what we learned in our initial training courses soon becomes dated and irrelevant. It has been estimated that the half-life of technical knowledge is about seven years. Furthermore, the amount of knowledge — and the amount of information — continues to increase. Materials Science and Engineering has become knowledge intensive: we have entered the knowledge-based economy.

In this new world, it is impossible for us to know all that there is to know, yet access to the knowledge base is increasingly readily available. So what will make good Materials technologists, rather than poor ones, is knowledge that is more relevant, and more current, and is applied more efficiently and effectively, together with a positive attitude towards updating this knowledge.

The workplace has also changed, with the result that Materials Scientists and Engineers are expected to have a wider range of skills (see Table 1 for three views on this). We increasingly work in teams on projects and much of what we do is virtual rather than tangible. As one project ends, another begins, and so we move from project to project, from team to team, and from one workplace to another. Indeed, for many, the increasingly itinerant nature of work leads to several different careers during a working life.

These are strong, compelling reasons for professional development skills, but there are many more!

- A better informed and more sophisticated public is demanding a higher duty of care and level of service from professionals;
- Linked to this is the increasing risk of claims for negligence from professionals deemed to have ‘failed’ in their duty or given poor advice;
- Within organisations, modern quality management systems demand that qualified people are in place to make decisions.
### Table 1: The skills required by professional engineers

**Table 1a**

<table>
<thead>
<tr>
<th>Skill</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combine general and specialist engineering knowledge and understanding to optimise the application of existing and emerging technology</td>
<td>Apply appropriate theoretical and practical methods to the analysis and solution of engineering problems</td>
</tr>
<tr>
<td>Provide technical, commercial and managerial leadership</td>
<td></td>
</tr>
<tr>
<td>Communicate effectively and possess good interpersonal skills</td>
<td></td>
</tr>
<tr>
<td>Apply appropriate codes of professional conduct, recognising obligations to society, the profession and the environment</td>
<td></td>
</tr>
</tbody>
</table>

*Source: UK Engineering Council*

**Table 1b**

<table>
<thead>
<tr>
<th>Skill</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transform existing systems into conceptual models</td>
<td></td>
</tr>
<tr>
<td>Transform conceptual models into determinable models</td>
<td></td>
</tr>
<tr>
<td>Use determinable models to obtain system specifications in terms of parametric values</td>
<td></td>
</tr>
<tr>
<td>Select optimum specifications and create physical models</td>
<td></td>
</tr>
<tr>
<td>Apply the results from physical models to create real target systems</td>
<td></td>
</tr>
<tr>
<td>Critically review real target systems and personal performance</td>
<td></td>
</tr>
</tbody>
</table>

*Source: UK Engineering Professors Council*
Table 1c

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Apply knowledge of mathematics, science and engineering</td>
<td></td>
</tr>
<tr>
<td>Use the technical skills and engineering tools necessary for</td>
<td>modern engineering practice</td>
</tr>
<tr>
<td>Design and conduct experiments, and analyse and interpret data</td>
<td></td>
</tr>
<tr>
<td>Design a system, component or process to meet specified needs</td>
<td></td>
</tr>
<tr>
<td>Function in multidisciplinary teams</td>
<td></td>
</tr>
<tr>
<td>Formulate and solve engineering problems</td>
<td></td>
</tr>
<tr>
<td>Interpret and employ guidelines on professional and ethical</td>
<td>responsibility</td>
</tr>
<tr>
<td>Communicate effectively</td>
<td></td>
</tr>
<tr>
<td>Apply knowledge of contemporary and cultural issues</td>
<td></td>
</tr>
<tr>
<td>Appreciate the impact of engineering solutions in the global</td>
<td>and social context</td>
</tr>
<tr>
<td>Work in teams or in collaboration with others</td>
<td></td>
</tr>
<tr>
<td>Develop information technology and management skills</td>
<td></td>
</tr>
</tbody>
</table>

Source: US Accreditation Board for Engineering & Technology

And so we need to learn continually as we work. This requires a skill set all of its own, a skill set we need to learn for ourselves as teachers and mentors, and a skill set we need to instil into our students for their future benefit.

What is professional development?

Professional development is the process by which a person maintains the quality and relevance of professional services throughout his/her working life. It has been defined by the Institute for Continuing Professional Development as:
‘The systematic maintenance, improvement and broadening of knowledge and the development of personal qualities necessary for the education of professional and technical duties throughout the practitioner’s working life.’

It follows that we have an ethical responsibility as professional Materials technologists to continue our professional development throughout our careers. Professional development is not a product, devised by training providers and academic institutions. It is a mindset, a habit to acquire.

Professional development requires self-directed, independent learning. It also demands an active rather than passive approach to learning. It differs from other forms of learning because it requires us to decide what needs to be learned or un-learned, how to learn it, and how to test and assess our learning. These are issues that we will discuss below.

**Effective professional development**

The European Society for Engineering Education (SEFI) issued a discussion document (Padfield et al., 1998) with the intention of stimulating debate on professional education and lifelong learning for engineers. This document defines professional development skills as the ability of the learner, fluently and without external direction to:

- Audit and assess what they already know and can do;
- Work out, at a level of detail that will differ from individual to individual, a career and a learning development plan;
- Integrate into their learning, acknowledgement of their need for continuing personal development in the private as well as the professional realms;
- Understand the qualities of different kinds of knowing, of understanding, and of skills and competences and understand how the different kinds of knowledge inter-relate and reinforce each other;
- Reflect upon their knowledge, establishing links between different kinds of knowledge, and formulating relevant theoretical constructs to explain it;
- Conduct research into elements of professional knowledge, practice and competence that lie within the context of their work, in pursuit of solutions to ‘problems of
the day’, personal professional development, and (more generally) the development of their profession.

The above is a list of ‘performance criteria’ by which we might assess our professional development skills. However, what is missing from the list is the route by which we might achieve these objectives or, of more relevance for this booklet, encourage our students to do so. We suggest that some or all elements of a five step approach could be used with students:

Step 1: profiling oneself

This is the starting point for an individual professional development plan and should contain the ingredients from the table below:

<table>
<thead>
<tr>
<th>Table 2: A basis for a personal profile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Working life (or study life, for a young student)</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Skills inventory</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Values, attitudes and beliefs</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Learning skills</strong></td>
</tr>
</tbody>
</table>

Developing this personal profile will make use of the reflective practices discussed in Step 5.

Step 2: define the strategy

Professional development needs to be correctly focused for maximum impact, so that it meets both our individual development needs and those of the organisation for which we work (see Table 3 below). If our employer has in place an annual staff review and appraisal process, then our individual aspirations and the organisational goals may have been reviewed, and a training and development plan agreed for the foreseeable future. Otherwise, we should discuss our professional development needs with our manager and our training or human resources department.
Table 3: The differences between a fragmented approach to CPD and a focused approach – based upon Willie (1991)

<table>
<thead>
<tr>
<th>Fragmented approach to CPD</th>
<th>Focused approach to CPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not linked to organisational goals</td>
<td>Linked to both organisational and individual needs</td>
</tr>
<tr>
<td>Seen as a cost not an investment</td>
<td>Viewed as an investment in human resource management</td>
</tr>
<tr>
<td>Focused on training (discontinuous) not development (continuous)</td>
<td>Focused on on-the-job development and skills development, in addition to knowledge-based training</td>
</tr>
<tr>
<td>Unsystematic</td>
<td>Evaluated with both pre- and post-course assessment</td>
</tr>
<tr>
<td>Menu driven, like ordering from a mail order catalogue</td>
<td>About ‘learning’ as opposed to ‘training’</td>
</tr>
<tr>
<td>About directive training and knowledge acquisition</td>
<td>Transferred to action and change in the workplace</td>
</tr>
<tr>
<td>Viewed as unimportant, with course attendance frequently cancelled due to pressure of work or lack of commitment</td>
<td>Flexible in application including open, distance and self-development</td>
</tr>
<tr>
<td>Not transferred, with learning rarely being implemented at the workplace</td>
<td></td>
</tr>
<tr>
<td>Viewed as a reward for good performance</td>
<td></td>
</tr>
</tbody>
</table>

Step 3: develop an action plan

Putting the strategy into action can be the biggest challenge. An action plan can help, but may be unfamiliar and uncongenial to a student. An effective action plan has four key ingredients:
• A clear statement of the goal to be achieved;
• The actions required to achieve the goal;
• The target timescale for achieving the goal;
• Criteria to assess when we have reached our goal.

In order to deliver the action plan, an employee will have to seek out opportunities for learning and skills development, ideally in partnership with the employer. In the university context, individual and team projects provide good environments for practice with action plans.

Having established an action plan, we next need to decide how we are to go about the learning process.

*Step 4: learning styles*

It has long been recognised that individuals each have their own preferred learning styles. There are many ways to categorize learning styles, but the simplest places learners into one or more of three categories.

• Visual: those who learn best through their eyes and what they see and read. The ideal learning approaches in this case will involve studying magazines and books and learning online;
• Auditory: those who learn best by hearing things, either on tape or in discussion. Dialogue and discussion is important to their learning process. The ideal learning environment is the classroom, but discussions with colleagues and audio tapes can also be useful;
• Kinaesthetic/Tactile: those who learn best by ‘doing’, such as taking their own notes or participating in demonstrations and hands-on projects. Ideal structure: magazine and online learning, classroom that encourages participation.

It is important to analyse the way we learn best before devising the learning strategy/action plan to achieve our goals. In some university programmes there is an explicit analysis of student learning styles, while in others this is uncommon. However the teacher needs to recognize the existence of, and adapt teaching to, a variety of preferred styles among the student body.
Step 5: evaluation and reflection

As we have seen, good professional development relies strongly on self-analysis and appraisal to develop a personal profile and to analyse preferred learning styles. This is not necessarily easy for a number of reasons. First, it can be hard to understand ourselves and ‘see ourselves as others see us.’ Second, reflecting on skills and competences is not something that student (or graduate) engineers are necessarily trained to do. Third, as the pace of life continues to increase, it is not easy to find time for self-analysis and reflection.

Mentoring is one way of overcoming these problems. A mentor is someone who can advise and guide a junior colleague in their career. He or she has a number of roles – as an appraiser, a supporter, a communicator and a motivator. The relationship therefore is different from that between a superior and his/her subordinate, but has many similarities to the relationship between tutor and tutee, or project student and supervisor.

Without a mentor, reflection is also not always a productive experience. It helps, of course, if we have a structure to our thinking. The key questions are:

- What is happening/has happened?
- What brought this about?
- What went well and what did not go well?
- How can the situation be improved?
- What might we learn from the situation that might influence future action?

It is a good idea to carry out this reflective evaluation both during and at the end of any task or period of learning. One way of encouraging reflective practice in our professional life is to keep a reflective diary or log, and this is now (in the form of Personal Development Planning, PDP) an integral part of many – indeed, in the UK, all – degree programmes. It is important to stress to the student that s/he should take care to include difficulties as well as successes in order to keep a balanced record of achievements.

As well as providing a focus for reflection on professional experiences, the reflective diary also has a role in helping us to evaluate the effectiveness of learning. Some useful questions are:
Was the learning task appropriate to our needs?
Was it efficient, achieving the desired outcome with the appropriate effort?
Was it economic?

Reviewing a reflective diary can also provide useful information. By looking back on experiences, we can reassess our goals. What have we accomplished? What should the next steps be? This leads us naturally back to revisit and update our professional profile and our action plan.

The development of professional skills before graduation and subsequent development as a professional engineer are a key part of professional formation. The crucial point for our students is that we should encourage them to see themselves, and then to behave, as embryonic professionals. If this is successful, then apparently dry activities such as PDP, technical writing and presentation skills will assume their rightful relevance and appeal.
Part 2: How you might teach it

The first point to make before discussing the delivery of teaching is that there is a lot of help available to you. You do not need to invent everything yourself, nor are you likely to have time to! In addition to this booklet and its parent book ‘Teaching Engineering’, a list of resources which are available to you at the time of writing includes:

- CORE-Materials [www.core.materials.ac.uk];
- UK Centre for Materials Education archived site [www.materials.ac.uk];
- The Cambridge Engineering Selector ‘Edupack’ [http://www.grantadesign.com/education];
- SteelUniversity.com [www.steeluniversity.com];
- AluMATTER [www.aluminium.matter.org.uk];
- MATTER [www.matter.org.uk];
- Networks initiated by the UK Centre for Materials Education (UKCME) and currently supported within the Granta series of conferences on Materials Education;
- International groups such as CDIO [Conceive, Design, Implement, Operate see: www.cdio.org], ICME [International Council on Materials Education, see: www.unt.edu/icme/];
- Journals such as IJEE, EJEE and Engineering Education.

Many ideas related to the teaching of engineering are discussed in the parent book ‘Teaching Engineering’. In the sections which follow we have tried to draw out some aspects of techniques which apply particularly well to the teaching of Materials.

**********
Problem Based Learning

James Busfield and Ton Peijs wrote the original guide based on their experiences in establishing Problem Based Learning (PBL) in the Materials programmes at Queen Mary, University of London. PBL is a concept used to enhance multidisciplinary skills using planned problem scenarios. It is an active way of learning that teaches students problem solving skills, while at the same time allowing them to acquire basic knowledge. PBL was first introduced in the late 1960s at McMaster University in North America, and has since spread around the world mainly in medical education.

The principal aims of implementing PBL are:

- To integrate knowledge and skills from a range of multidisciplinary modules;
- To acquire knowledge through self-study;
- To teach students how to work in groups and manage group projects;
- To improve and develop transferable skills of students;
- To develop problem solving skills of students;
- To encourage self-motivation, curiosity and thinking;
- And finally, to make learning fun!

At Queen Mary for the first year students, the PBL programme consists of 6 problems\(^1\) (3 per semester) and some initial sessions of key-skills training, as well as some miscellaneous lectures that are beneficial and essential to the development of students. For second year students, PBL consists of 4 problems (2 per semester) and some key-skills sessions that prepare them with skills required in order to complete PBL tasks.

There is a sample PBL problem in the Example Case Studies section (Part 5).

In PBL two different roles for teaching staff can be distinguished:

\(^1\) Busfield and Peijs used the term ‘case study’. We have changed this to ‘problem’ in order to reduce confusion with Davis’s section on Case Studies.
The case group tutor who works with a specific PBL group;

The problem champion who creates a specific problem exercise.

During the problems, PBL groups meet regularly for at least an hour each week. There are no compulsory times and locations for these meetings; it is up to the individual groups to decide when and where to meet. However, it is a requirement for all members of each group to meet up at least once a week with their case group tutor. Attendance at all these group meetings is compulsory and is registered by the case group tutor.

Learning Outcomes

PBL in the Department of Materials at Queen Mary is conceived as a way of reinforcing the traditional lecture-based process of delivering academic content, and it is not designed as a substitute. It is primarily a problem-solving programme that seeks to provide students by the end of Year 2 with a checklist of transferable skills and underpinning subject-specific knowledge for more detailed project/research work and further study/application in subsequent years.

By completing PBL, students are expected to learn how:

- To solve problems in an organised manner using brainstorming and resource investigation techniques;
- To build on prior knowledge and acquire new knowledge throughout the problem;
- To operate basic lab equipment (microscopes and mechanical testing machines) to support the problem investigations;
- To use basic computer packages (Word, Excel, and PowerPoint) and engineering analyses packages (CAE and FEA);
- To analyse and discuss experimental data using written reports, posters and oral presentations;
- To work in groups by managing group meetings and recording them using formal minutes to note all actions and decisions.
The Problem Champion

Each PBL problem has a champion who conceives the problem, puts it onto paper, gives a verbal and written explanation for tutors, and assesses how PBL student groups deal with the problem. It is important that students are able to contact the problem champion at designated times during the period in which the problem is being completed.

Perspective Adopted: The 7 Step Project Plan of PBL

The following stepped plan approach – or something similar – is essential in order to ensure that a systematic method of working is used for all the problems. Thus group meetings should be structured to conform to the following 7-step Project Plan:

- Step 1: Explain unknown wording, statements and concepts;
- Step 2: Define the problem(s);
- Step 3: Brainstorm – analyse/try to explain the problem(s);
- Step 4: Make a systematic inventory of explanations;
- Step 5: Formulate self-study assignments;
- Step 6: Perform self-study assignments;
- Step 7: Report & evaluate on self-study. After each group meeting, the group formulates the next stage of self-study assignments.

Step 1: Explain unknown wording, statements and concepts
First, students will read the problem outline, and then they should identify any words, terms or concepts whose meaning they are unclear about. Other student members of the group may be able to provide definitions. It is important that students feel safe to be frank about what they do and do not understand.

Output: Words on which the group cannot agree a meaning should be listed as learning questions.

Step 2: Define the problem(s)
Students are encouraged to contribute their views concerning the nature of the problem. The tutor may need to encourage them all to contribute in a broad discussion. It is quite possible for different group members to have a different perspective of the problem. Comparing these views helps to define the task ahead.

Output: List of problems.
Step 3: Brainstorm
This is the most crucial step in the problem solving process. Here students test out a wide variety of possible explanations or solutions for the problem using information from memory. With brainstorming, each member of the group makes suitable suggestions, until no more ideas are forthcoming. Initially, no priority is set for the suggestions and all ideas are viewed as being equally valid no matter how strange they may appear at first.

The ‘scribe’ writes down all possible ideas that contribute towards understanding, explaining and solving the problem on a whiteboard or a large sheet of paper. Only after all the ideas are written down can they be discussed in more detail and priorities can be set. The tutor should discourage students from going into too much detail during the brainstorming phase. This step is essential as it encourages students to come up with different solutions to the same problem.

Output: List of possible explanations or solutions.

Step 4: Make a systematic inventory
Here the group re-examines the ideas raised in the brainstorming in more detail and compares their ideas against the problem outline to see how well they match, which solutions are linked and where further exploration is needed. This step will help define the self-study assignments of Step 5, as the group needs to organise the different explanations and solutions to form a limited number of tentative solutions.

Output: Ordering or linking of possible solutions from brainstorming.

Step 5: Formulate self-study assignments
The group agrees on a core set of learning objectives, often in the form of questions, which form the basis of students’ self-study. These learning objectives should be specific and achievable within the time available between two group meetings. At the beginning of a problem (after the first meeting) it is important that all students share the self-study assignments, whereas in a later stage of the problem some students may have assignments that are not shared by the whole group.

Output: The written objectives are the main output of the group after each group meeting. These are circulated to all students and the tutor immediately after the meeting.
Step 6: Perform self-study assignments
In this step, the students will individually seek out any available learning resources to obtain the information that will contribute towards understanding, explaining and solving the problem. It should be emphasised that each student is responsible for their assignment and must be prepared to contribute to solving the problem. After each group meeting, the group will formulate the next stage of the self-study assignments.

For some PBL problems, students (as a group) will be requested to undertake experimental investigations to support their problems. In these instances, it is essential that students liaise with appropriate lab staff identified by the problem champion prior to booking a time slot to use lab facilities relevant to their problem.

Output: Students’ individual notes.

Step 7: Report and evaluate on self-study
In the second meeting, the group returns to discuss the self-study assignments. Each student reports on the outputs of their study, shares information about sources, helps each other understand, and identifies problem areas that need further study or expert help.

Output: Students’ individual notes.

Whenever a problem is completed with a written group report and/or a presentation, then the draft version of the report or presentation needs to be discussed during the last group meeting of that problem.

PBL Group Roles

In the first year, the initial group selection for the first two problems is determined by merging two tutor groups. For at least one of the two problems, a student’s individual tutor will also act as their case group tutor. After this, the groups will change on a random basis. This ensures that any effect of group selection is evened out over the first two academic years. Average group size is five or six members.

By rotation at each meeting, students play four specific roles within the group. These are chair, minutes-secretary, scribe and general group members. Rotation ensures that students are exposed to all of these roles.
During a group meeting, the chair has the task of maintaining the agenda and steering the conversation. In order to have information available to the entire group, it is useful to keep a record as part of the work on a problem. The scribe does so by taking down important matters on a white board, flip chart or large sheet of paper. The information addressed in a student group must be incorporated in minutes of the group meeting. This facilitates the recording of a problem, and is part of the process of ensuring that the group functions well. During each group meeting, one of the students therefore acts as secretary.

**Role of Chair**
- To lead the group through the 7 steps of PBL;
- To ensure equal participation of all group members;
- To maintain good group dynamics;
- To keep time;
- To ensure the group sticks to the task at hand;
- To check if the scribe records the points raised in the discussion.

**Role of Minutes-Secretary**
- To make minutes of meetings by structuring points written down by the scribe;
- To distribute the minutes of the meeting to all group members and the tutor;
- To participate in the group discussion.

**Role of Scribe**
- To record points raised by the group;
- To help the group order their thoughts;
- To participate in the group discussion.

**Role of Group Member**
- To follow the 7 steps of PBL;
- To actively participate in the group discussion;
- To listen to each other's contribution;
- To ask open questions;
- To research all the learning objectives independently;
- To share information with each other.
Prior to each group meeting, an agenda is made. After every meeting is held, minutes are written and circulated. During the meeting the agenda should be followed systematically.

The standard agenda for the first group meeting is given below:

- Meeting commences (assign meeting roles);
- Apologies for absence (only in very exceptional circumstances);
- Step 1: Explain unknown wording, statements & concepts;
- Step 2: Define the problem(s);
- Step 3: Brainstorm;
- Step 4: Make a systematic inventory;
- Step 5: Formulate self-study assignments;
- Close the meeting.

The model agenda will be changed or altered depending on the progress of the problem. The following agenda is suitable for most of the subsequent meetings, (during the meeting the agenda should be followed step by step):

- Meeting commences (assign meeting roles);
- Apologies for absence (only in very exceptional circumstances);
- Review the minutes of the last meeting to remind what should have been done;
- Step 1: Report on self-study activities assigned at the last meeting;
- Step 2: Review the definition of the problem(s);
- Step 3: Brainstorm for new ideas;
- Step 4: Make a systematic inventory;
- Step 5: Formulate further self-study assignments;
- Close the meeting.

Other items might have to be added at certain specific meetings. For example, the tutor should conduct a mid-project review on each of the group members’ individual performance before the close of one of the meetings. Also, in the final meeting, an item should be included where the tutor can review the group’s draft PBL submissions, to ensure that no factual errors are contained and to give advice on presentation and style.
Writing Minutes of Group Meetings

After every meeting, minutes are written by the minutes-secretary (using the format given below), and then typed up and circulated before the end of the day to all participants in the group including the case group tutor.

The minutes are a record of how the PBL problem progressed, and will be submitted with the other submissions at the end of the PBL activity for assessment.

Below is a model for writing up meeting minutes for a normal meeting. The format will change depending on the progress of the problem. For example, for the first and last meeting during a problem the agenda will need special issues for those meetings.

Minutes of Meeting:

- **Context**: PBL group number; date and time of meeting; title of problem; number of meeting;
- **Opening**: List of attendees; agreement on different roles of group members (change at each meeting);
- **Announcements of group members or tutor**;
- **Minutes of previous meeting**: Discuss issues arising from the minutes of the previous group meeting;
- **Step 1: Report on self-study activities assigned at the last meeting**. Outline the self-study report from the group members;
- **Step 2: Review the definition of the problem.** Write down any changes that may have been agreed since the last meeting;
- **Step 3: Brainstorm for new ideas**. Write out all the main ideas that came up in the meeting;
- **Step 4: Make a systematic inventory**. Prioritise the ideas raised during the brainstorming;
- **Step 5: Formulate further self-study assignments**. Assign individuals to specific study assignments for group members;
- **Close the meeting**: Record time of closure; plan time and location of next meeting.
Role of the Problem Group Tutor in PBL

During the problem, a tutor works with each PBL group. This person is usually an academic member of staff or a research assistant in the department. As tutor to the group, they have several tasks. They should:

- Facilitate group interactions amongst students;
- Consider ways of improving co-operation in the student group as an instrument for attaining the problem goals;
- Listen carefully to what students already know and stimulate them to tackle possible new challenges;
- Ask questions and provoke discussion;
- Explain how the material is organised;
- Monitor progress and performance.

The overall role of the tutor is:

- To stimulate the group at appropriate moments to explore the material in more depth;
- To act as facilitator of the group learning process;
- To provide formal moderation of the individual students within the group.

Tutors should never:

- Act as the chairperson;
- Lecture in the traditional sense;
- Impose their knowledge and standards on the group, but help the students explore the problem on their own.

Tutor Instructions

Prior to the start of the problem, tutors should:

- Check the scheduled PBL timetable at the start of the academic year and note when they are expected to be a tutor;
- If any significant periods of planned absence overlap with their tutoring commitments, then the tutor is expected to swap their tutoring role with a colleague and inform the PBL problem champion of the change;
In the week prior to the start of the specific PBL exercise, they should read the briefing documents provided both for students and for the tutors, which will be circulated by the problem champion.

During the initial case briefing session, tutors should:

- Attend so that they can confirm what the students have been told;
- Introduce themselves at the end of the session to their group;
- Arrange the initial group meeting at a time and location that is convenient for the whole group. Typically this will be on the day of the briefing session.

During the group meetings, tutors should:

- Ensure that a chair, minutes-secretary and scribe are selected, and that they know their respective roles;
- Stimulate the conversation by asking open questions (e.g. how? what? why? when? where?) that will enable the group when appropriate to explore the material in more depth;
- Support the group learning process;
- Prevent too much sidetracking;
- Encourage less vocal members to participate;
- Maintain good group dynamics and resolve any significant disputes;
- Record the attendance of the group;
- Complete the Meetings Review Form (Appendix 1) for the case group at each specific meeting;
- Ensure that subsequent follow up meetings have been arranged;
- Evaluate group performance;
- At a subsequent follow-up meeting the tutor should perform a mid-project review, whereby the students are given feedback on their own contributions to the group;
- At the final meeting the tutor should review the draft PBL submissions such as a presentation or report. Then they should point out any obvious factual errors and provide advice on style and format of the final submission.
At the end of the problem, the tutor should:

- Attend the formal assessment event (presentation, trial, poster session or other evaluation);
- Produce a mark for each of the groups they observe at the formal assessment event and return the completed *Assessment of Presentations Form (Appendix 2)* to the case champion;
- Collect from the students in their PBL group individual *Peer Assessment Forms (Appendix 3)* and collate the marks;
- Complete the *Case Group Assessment Form (Appendix 4)* and return them to the problem champion at the end of the session.

Note that the tutor is also responsible for moderating the individual scaling factor generated from the peer review process. This should reflect each individual performance, with consideration given to the feedback from the Peer Assessment Forms completed by all the students at the conclusion of each project, as well as reflecting their own observations recorded on the *Meetings Review Form (Appendix 1)*.

**Assessment of PBL**

The problem group is typically expected to submit one or a number of the following at the completion of each project: a poster, report, oral presentation, web pages, or design and build device. The specific format will be identified on the initial problem outline. The problem champion will assess the work to generate a group mark.

Each individual’s performance is reviewed using the peer review process to generate an individual scaling factor for each student. This is done by each student completing a *Peer Assessment Form* at the conclusion of each project. This is handed to the problem tutor at the formal assessment event.

The problem tutor is responsible for moderating the individual scaling factor generated from the peer review process. This should reflect each individual performance with consideration to the feedback from the students. Each tutor should then complete a *Case Group Assessment Form* for their group that should be handed over to the problem champion.
The problem champion collates all the group marks and the scaling factors to generate individual marks for the PBL problem. Tutors are encouraged to differentiate between individual performance marks, and should note that the marks should not alter the average mark obtained by the group. Therefore the average of the multipliers for the whole group must be 1.00. For example, if a tutor wants to award a higher mark to a member of the group, then one or more members’ marks must be reduced by a similar amount.

Suggested scaling multipliers are:

- Non-participation: 0.0
- Poor: 0.75
- Average: 1.0
- Good: 1.1
- Excellent: 1.25

As an example for a problem that required a report and a presentation to be completed then the typical individual mark is derived from:

\[
\frac{(\text{report} + \text{presentation})}{2} \times \text{individual scaling factor}
\]

Each individual in the group will be assessed upon how well they demonstrate the following attributes:

- To analyse the problem;
- To innovate possible solutions;
- To critically evaluate group suggestions;
- To demonstrate prior theoretical knowledge as well as that newly acquired throughout the problem;
- To use practical skills in completing the problem.

In addition, their team roles will be evaluated, including how well they performed as:

- Chairperson;
- Minutes secretary;
- Scribe;
- Group member.
PBL Submissions

Written Report
A single submission for each group is frequently (but not always) expected for a problem. The report should be:

- Structured;
- Include details of any experimental work undertaken;
- Include plots/tables of all the essential discoveries during the investigation;
- Include notes of all group meetings as a record of how the PBL problem progressed.

Presentation
Students may be asked to carry out a group presentation on their findings. Typically only 1 to 3 members should actually make the presentation. But throughout the year, every student is expected to have presented their findings at least once. Presentations are restricted to 10 minutes each, with 5 minutes for questions, and immediate feedback is provided on team performance.

Poster
Occasionally, the formal assessment can be based upon a poster presentation. This should be clear, concise, attractive, and easy to read.

Web Resource
Occasionally, students are asked to create a web-based report to explain their findings. This should incorporate colourful graphics and should be easy to navigate. Again, only a single web-based report per group is to be submitted.

Design and Build-Based Study
Occasionally, students in their groups are asked to make a device or structure as part of a problem. This must be submitted at the end of the study period for either evaluation or testing.

For further information regarding PBL at the Department of Materials at QMUL, please visit the following website: http://www.materials.qmul.ac.uk/pbl

**********
Case Studies

The original booklet by Claire Davis and Elizabeth Wilcock emphasized that teaching and learning styles are changing, and pointed out that in recent years there has been a noticeable move from lecture-based activities towards more student-centred activities. Case studies are an increasingly popular form of teaching and have an important role in developing skills and knowledge in students. In this section we explore the use of the case-based approach to support engineering education and, more specifically, its role in Materials Science related higher education courses. This includes looking at the ‘traditional’ Materials Science and Engineering courses as well as the more multidisciplinary courses (e.g. Biomedical Materials Science, Sports and Materials Science etc.).

We try to highlight the good practice identified at Birmingham, and also discuss our experiences (both good and bad) of the adoption and implementation of this type of learning activity. We hope that by explaining our rationale for the adoption of case studies, and by discussing their development and structure, you will be encouraged to consider your own teaching methods and whether this approach, or aspects of it, is appropriate to you. Part 5 of this booklet includes a few examples of case studies that illustrate some of the different topics discussed below.

What is a case study?

It is now well documented that students can learn more effectively when actively involved in the learning process (Bonwell and Eison, 1991; Sivan et al, 2001). The case study approach is one way in which such active learning strategies can be implemented. There are a number of definitions for the term case study. For example, Fry et al (1999) describe case studies as complex examples which give an insight into the context of a problem as well as illustrating the main point. We define our case studies as student-centred activities based on topics that demonstrate theoretical concepts in an applied setting. This definition of a case study covers the variety of different teaching activities we use, ranging from short individual case exercises to longer group-based activities.
It is at this point that it is important to make a distinction between this type of learning and problem-based learning (see previous section). The structure and format of the case studies used here can be likened to project-based learning as described earlier, and by Savin-Baden (2003). Savin-Baden highlights the differences between problem-based learning and project-based learning and these can be summarised as follows:

**Table 1: Differences and similarities between project-based learning (similar in structure to case study learning) and problem based learning**

<table>
<thead>
<tr>
<th>Project-Based Learning</th>
<th>Problem-Based Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predominantly task orientated with activity often set by tutor</td>
<td>Problems usually provided by staff; but what and how they learn defined by students</td>
</tr>
<tr>
<td>Tutor supervises</td>
<td>Tutor facilitates</td>
</tr>
<tr>
<td>Students are required to produce a solution or strategy to solve the problem</td>
<td>Solving the problem may be part of the process; but the focus is on problem-management, not on a clear and bounded solution</td>
</tr>
<tr>
<td>May include supporting lectures which equip students to undertake the set activity, otherwise students expected to draw upon knowledge from previous lectures</td>
<td>Lectures not usually used, on the basis that students are expected to define the required knowledge needed to solve the problem</td>
</tr>
</tbody>
</table>

In practice there is overlap between the two teaching modes and we should not worry too much about clear distinctions. Many of the discussion points in this section will be relevant to both case studies and problem-based learning topics.

**Why use case studies in teaching?**

The discipline of Materials Science and Engineering is ideal for using case study teaching because of the wealth of practical, real life examples that can be used to contextualise the theoretical concepts. Educational research has shown case studies to be useful pedagogical tools. Grant (1997) outlines the benefits of using case studies as an interactive learning strategy, shifting the emphasis from teacher-centred to more student-centred activities. Raju and Sanker (1999) demonstrate the importance of using case
studies in engineering education to expose students to real-world issues with which they may be faced. Case studies have also been linked with increased student motivation and interest in a subject (Mustoe and Croft, 1999). In our experience of using case studies, we have found that they can be used to:

- Allow the application of theoretical concepts to be demonstrated, thus bridging the gap between theory and practice;
- Encourage active learning;
- Provide an opportunity for the development of keys skills such as communication, group working and problem solving;
- Increase the students’ enjoyment of the topic and hence their desire to learn.

Many courses already have some case study teaching in them, and we have introduced a case-based approach in all of our courses for the above reasons. We have found the use of case studies to be very beneficial, not only to the students but also to our lecturers who have found the learning/teaching experience enjoyable and challenging. Students’ comments include:

‘Well, it’s real stuff isn’t it? Otherwise you can feel like you’re just doing something for the sake of it. When you do a case study you go out and find information that is being used in real life.’

‘It’s something different where you actually apply what you’re learning.’

Did we find it hard to introduce case studies into our teaching?

In our experience, an important factor in the introduction of case studies into a course is the style or structure of the course itself. We offer a number of separate courses in our School at Birmingham and have recognised that they fall into two distinct types (defined here as Type I and Type II). Type I courses are the traditional Materials Science and Engineering degrees which are accredited by the Engineering Council and can lead on to Chartered Engineer status. We also offer multidisciplinary courses (Type II courses) such as Bio-Medical Materials as well as Sports and Materials Science. These courses are not accredited and
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admit students with a wider range of background skills, varied academic qualifications and different career aspirations. Overall, we have found it easier to introduce case studies into our Type II courses and therefore these courses contain a greater proportion of this type of learning. A summary of the differences between these courses is given in Table 2.

Table 2. Differences between traditional, established Materials Science and Engineering degree courses (Type I courses) and the newer (often multidisciplinary) Materials related courses (Type II courses)

<table>
<thead>
<tr>
<th>Type I courses</th>
<th>Type II courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content mostly selected to meet accreditation requirements</td>
<td>Non-accredited courses</td>
</tr>
<tr>
<td>Well established courses with existing lecture content</td>
<td>New lecture content often required (for at least part of the course)</td>
</tr>
<tr>
<td>Students more likely to have a physical science background (maths, chemistry, physics)</td>
<td>Students likely to have a mixed subject (arts + sciences / vocational) background</td>
</tr>
<tr>
<td>Tends to be more theory-based</td>
<td>Tends to be more application-focused</td>
</tr>
</tbody>
</table>

Other issues that relate to introducing case studies in our courses (other than due to syllabus/accreditation constraints) are as follows:

- Some lecturers had been teaching their modules for a long time and were reluctant to change the tried and tested formula. Others, however, were keen to experiment with different types of learning as opposed to the traditional ‘talk and chalk’ method. Those who were open to new types of teaching were generally more involved in the planning and teaching of the newer courses.

- Where case studies have been included in place of lectures and practicals covering similar topic areas in our traditional courses, we initially did not replace sufficient existing time-tabled teaching to allow for students to carry out background reading and additional research. We have now rectified this.
We have found it easier to increase the number of case-studies running in our courses in a gradual manner as we identify the resources, time and support that is needed.

How do you develop a case study?

There are a number of ways to develop case studies, some more successful than others. The following list covers the main methods and also discusses other options and experiences external to our institution.

- **Developing a case study based on the research interests of staff.** For example, the research area of one of our lecturers is polymeric foams; he is now responsible for a Sports and Materials Science case study analysing running shoe performance including the behaviour of the polymeric foams in the soles. We have found this to be a good method of case study development, as it is easier to locate resources for the case study, and the lecturer’s in-depth knowledge and interest in the topic add to the case study.

- **Requesting students to develop case studies based on personal interests.** This is a method we have not tried, but is an interesting way to develop case studies and one promoted by Smith (1992). However, problems may arise when trying to involve students. For example, the University of Bath produced a portfolio of case studies to support recruitment and teaching of their undergraduate courses in Materials Science and Engineering and initially approached the students for ideas. They ran a competition where undergraduates and postgraduates were invited to submit proposals and a prize of £250 was offered. Unfortunately, this was not as successful as anticipated and students did not take part in the competition. This may be because the students did not have enough confidence in their abilities to develop a case study or felt they did not have the spare time to work on the topic, particularly as many students take part-time jobs to help finance their studies. A more focused approach of asking postgraduate students, and graduates from the department, to develop case studies based on their experiences / projects is now being pursued.
• **Develop from scratch, maybe following interests/ideas picked up from elsewhere.** This approach may involve contacting or visiting other institutions to find out what methods and topics they are using.

• **Invite external lecturers, for example from industry, to develop, or contribute to, a case study.** Involving external sources can add new dimensions to the learning activity. One of our case studies looks at materials used in tennis equipment and we invite a tennis coach to brief the students on the topic at the start of the case study. This has been well received by the students who felt it added further insights into the topic. Another approach is to use real-life examples from industry such as described by Raju and Sanker (1999), for example by inviting practising engineers to present examples in the form of a case study. Care is needed if an external lecturer is asked to develop the entire case study to ensure they understand what is being requested of them.

• **Developing a case study to replace more traditional teaching on the same topic.** For example, we now run a case study on joining processes, which contributes to a third of a module in level 2 (see case study example C9). The topics covered in this case study were previously taught through lectures. We decided to adapt this part of the module to a team case study approach that is continuously assessed with no examination question.

**Use of case studies to develop key skills**

We have found the case-based approach to be a useful method to develop transferable skills. Key skills we have embedded into our case studies include:

• **Group working.** The benefits of group working are well documented, and we have found that a team case study approach can add to the learning experience. In our Sports and Materials Science course group work has the added benefit of allowing students to share their personal knowledge and experiences of sport (many students on this course play sport to a high level). Care is needed with group working activities e.g. selecting group membership to ensure smooth group operation / training students in
group working skills. This is particularly important for longer case studies.

- **Individual study skills.** Case studies are a good vehicle for encouraging students to carry out independent research outside of the lecture/tutorial environment.

- **Information gathering and analysis.** Many case studies require resource investigation and encourage students to utilise a number of different sources, i.e. internet, library, laboratory results and contacting experts in industry.

- **Time management.** Longer case studies require students to really consider how best to carry out the work so that it is completed to the set deadline. Interim meetings with academic staff ensure progress is made during the case study rather than all the work being left to the last week.

- **Presentation skills.** Most of our case studies require students to present their work in a variety of formats; these include oral presentations, articles, posters and reports.

- **Practical skills.** Some of our case studies involve practical work on the components that are being studied. Feedback has shown that many students enjoy the hands-on approach.

**Assessment types for case studies**

Our case studies encourage learning of both course content and key skills, and careful consideration needs to be made as to how to assess these different aspects. The two main modes of assessment are formative (assessment for the purpose of improving learning and student performance) and summative (evaluation of student performance against a set of predetermined standards). We use summative assessment to assess the students’ understanding of course content, yet realise that a more formative approach is necessary for evaluating key skills development and giving feedback to encourage students to reflect upon their learning experience (see sections on Assessment and Evaluation in Parts 3 & 4 of this booklet).

Group assessment is another area we have had to consider, as many of our case studies are group-based. Learning to collaborate...
is a useful skill and the ability to produce a group output is an important part of this. In terms of summative assessment, these case studies require students to produce one or more outputs between them (generally a report and/or presentation/poster) and we have used group meetings with supervisors and feedback sessions to provide the formative assessment. In order to produce an individual student mark, we use confidential peer assessment forms and/or an individual executive summary to go with the group output. Refer to the parent book [http://www.materials.ac.uk/guides/casestudies.asp] or back to the PBL Section in Part 2, for more ideas on the assessment of individuals in groups.

**Are case studies a good learning approach for all students?**

It should be acknowledged that styles and modes of learning vary from student to student. Our case studies are predominantly coursework-based; however, this style of work may not be suited to everyone. Some students may work more efficiently in a formal and time-constrained setting, such as an examination, and although this may not be the better mode of learning, it is one to which they have become thoroughly accustomed at school. One way in which we have tackled this, in some of our case studies, is to have both coursework and exam assessment on the case study content. Provided that a balance in learning styles is maintained in the overall course then the students are able to develop a range of skills and no student should be unfairly disadvantaged compared to another.

Group working may also not be suited to all students. Our feedback on group work has shown that this presented a particular problem for some students. Most students recognise its importance for developing key skills, but many commented on the uneven workload within their groups. Comments included:

‘It’s not fair when other members of the group do not provide any input or aid the group effort yet still get marks…’

‘I don’t like working as part of a team because there are always lazy people who don’t do any work and if you don’t want that to affect your own mark you end up doing everything. I work well in a team and am quite a good organiser, but tend to do too much of the work.’
In response to this feedback, we developed a way of tackling the issue of uneven workload. We piloted formal group sessions with the lecturer in one of our case studies (see case study example C7 for details). Student feedback was positive and we feel that this has gone part way to helping the students. Positive comments have included:

‘They (the group sessions) enabled the group to set specific targets and identify the roles of each individual.’

‘A good way of motivating people to actually do some work and not to leave it to the last minute!’

Common pitfalls

Feedback from both staff and lecturers has highlighted areas for improvement in our case study teaching. Some of these will equally apply to other forms of teaching, for example problem-based learning, small group tutorials, project work etc.

- **Group working.** The subject of group working comes up time and time again in student feedback. We originally provided no formal training for group work and soon recognised that this was an area we needed to address. We have developed a case study for some level 1 students that incorporates group training including discussion of group dynamics, group functioning and group meetings. As outlined earlier, we also feel that formal group sessions are helpful for the students, particularly for longer case studies.

- **Explanation of case study requirements.** Feedback has shown that students would like more details on what is expected from them in the case studies e.g. level of independent research and, more specifically, sufficient information on how to write reports, give presentations and design and present posters. This is particularly important at the start of the course as for many students this may be a very different form of learning to what they were used to at school. For example, one student commented after a case study, ‘A better brief for the poster would have limited the text content, and a clear aim for what needs to be included would have been helpful’. We have now compiled tips and suggestions for students in these areas, which form part of our case studies support web-site.
• **Depth of learning.** When examining student use of resources, we found that many of the research-based case studies led students to derive all their information from the Internet. Whilst this is a valuable resource we feel that it can often result in only surface learning. We have found that one way of addressing this is to specify to students that we are expecting critical analysis in their work. Including a practical component is also a useful way of achieving more in-depth study (see case study C7). Ensuring that there is progression of learning skills development (e.g. analysis to synthesis etc.) when using a series of case studies is important, rather than repetition of the same skills.

• **Case study mark allocation.** We have had to consider how many credits/marks should be allocated to our case studies. We have found that some students have spent quite a lot of time carrying out independent research yet felt that they have not received enough credit. Greater guidance was required as to how the marks were allocated.

• **Added workload i.e. not replacing sufficient other teaching.** In some cases, where we have replaced existing teaching with case studies we have found that students were actually spending more time working towards the case study than they would have spent in the original mode of learning. Whilst it is encouraging to see such dedication to the topic, we realise that it is important not to overload students with case study work that could compromise being able to complete assignments in parallel modules.

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Laboratory Classes

In the original booklet, Caroline Baillie and Elizabeth Hazel's approach was based on the role of laboratory work as an essential element of education in Material Science and Engineering. In the laboratory, students can explore their understanding of the subjects being taught by placing their learning in context. Students can also be motivated to learn in the laboratory context if they can feel a spirit of excitement when investigating a scientific phenomenon, or when creating something that actually works. Many of us can remember an occasion where a laboratory class was particularly memorable or enlightening. We can also probably remember many hours of tiresome exercises which seemed to teach us very little. The design and delivery of laboratory classes, and the forms of student assessment used in them, need to be examined critically for their contribution to effective student learning.

What do you want your students to learn in the lab?

Goals and Potentials
There is much agreement in the literature on the following range of goals for laboratory work (Ramsden, 1992; Boud, Dunn, & Hegarty-Hazel, 1989):

1. Learning scientific information and concepts;
2. Participating in the construction of scientific knowledge, understanding the interplay of theory and methodology;
3. Understanding the processes of scientific enquiry and appreciating and emulating the role of scientists and engineers in enquiry:
   - Observing and measuring;
   - Seeing a problem and seeking ways to solve it;
   - Interpreting data and formulating generalizations;
   - Building, testing and revising a theoretical model.
4. Developing imagination and creativity;
5. Learning manipulative and technical skills and the use of equipment;
6. Developing relevant professional values, attitudes, and interests;
7. Developing an orientation to the social, historical and philosophical aspects of science and engineering;
8. Appreciating the application of knowledge and methods;
9. Developing literature skills;
10. Learning how to communicate verbally and orally;
11. Learning to work co-operatively with colleagues, developing teamwork;
12. Developing scientific or engineering attitudes.

Problems with achieving these goals
At the same time as reaching some agreement on the potential goals for laboratories, there is also much agreement that only sometimes is the potential of laboratories fulfilled. The following problems have been highlighted in the literature (Boud, Dunn, & Hegarty-Hazel, 1989):

- Many of the goals are not exclusive to the laboratory and may be attained more efficiently elsewhere;
- Laboratory programmes, and especially their assessment, may emphasize low-level goals at the expense of higher-level goals, and may encourage students to concentrate on methodology without an understanding of the interplay of theory and methodology;
- Assessment often fails to provide evidence of whether learning goals are attained or not, and it may be possible for students to do well in a course without even attending a laboratory;
- Many laboratory classes have too many, too diffuse aims and it would be better to do a few things well;
- Students often find labs tedious and boring and do not take them seriously;
- Frequently, poorly trained demonstrators turn a hands-on lab experience into a demonstration.

How do you design and teach lab classes to achieve your goals?

There are several different ways of presenting laboratory work and they differ greatly in purpose and degrees of student autonomy. In order of decreasing teacher control and increasing student autonomy, these are controlled exercises, experimental investigations and project work. The differences can be recognised using the simple but sound scheme in Table 1 which analyses the level of openness for scientific enquiry in different laboratory exercises (adapted from Herron, 1971; Boud et al, 1989).
Table 1: A Way of Reflecting on Student Laboratory Exercises

<table>
<thead>
<tr>
<th>Type of laboratory</th>
<th>Level of enquiry</th>
<th>Aim</th>
<th>Material</th>
<th>Method</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demonstrations</td>
<td>0</td>
<td>Given</td>
<td>Given</td>
<td>Given</td>
<td>Given</td>
</tr>
<tr>
<td>Controlled exercises</td>
<td>1</td>
<td>Given</td>
<td>Given</td>
<td>Given</td>
<td>Open</td>
</tr>
<tr>
<td>Structured investigations</td>
<td>2</td>
<td>Given</td>
<td>all or part</td>
<td>Part given or open</td>
<td>Open</td>
</tr>
</tbody>
</table>

**Controlled Exercises**

These are activities which are wholly designed by the teacher and are often thought of as verification exercises. They can be completed by a student within a short time-span, typically one or two laboratory periods. There is a known outcome and if students follow the instructions, they should arrive at that outcome (more or less).

**Advantages of controlled exercises**

They can provide introductory experience with the materials and processes of a discipline, equipment, apparatus, organisms, and chemicals, as appropriate. In many disciplines, the whole procedure has become very well honed. Teachers who wish to use controlled exercises with their students can often locate suitable experiments in laboratory manuals from their own student days, in commercial texts, or in discipline-specific education journals. For faculty, a major appeal of using controlled exercises is the ease of finding them and the charm of their predictability. They can be used from year to year with minimum fuss.

**Disadvantages of controlled exercises**

A major disadvantage is that students often do not like controlled exercises very much, finding them dull and tedious. Students may not be very sympathetic towards the elegance of exercises nor regard their lab work as a microcosm of experimentation. They can find the pre-lab work a meaningless ritual, the introductory talks and the controlled exercises as lacking personal satisfaction or connection to their world. Results and reports from students in previous years are often readily available and there is the temptation for the task of writing up to become one of ‘faking good’ the results.
Examples of controlled exercises
An example of a controlled exercise which students found boring and alienating is the following from a Materials Science lab where students are expected to learn about the properties of polymers; specifically how polymers behave under different conditions. The students are asked to conduct a series of tests to explore the properties of polymers. They are given samples of a specific size established by standards and asked to test them in tension using a tensile testing machine. Usually they would not do the tests themselves, but watch whilst a technician conducts the tests. After the samples of a range of polymers have broken, the students are required to calculate the basic properties of each material. An assignment is to write the experiment up, with the emphasis being on presentation and producing results of the right order of magnitude. In all, there is little or no opportunity for the students to engage with the techniques or to relate the exercise to their world.

By contrast, the following is an example of a controlled exercise which students found more engaging. It is on the same topic, how polymers behave under different conditions. Students are asked to test the bouncing power of squash balls at different temperatures, including first dropping them into liquid nitrogen. One student described it as an experiment which he found useful and which captured his imagination. He said the students had fun and got a physical feel for the glass transition temperature and its relation to mechanical properties. Here the squash balls are something that most students recognise. Both the balls and the use of liquid nitrogen have about them an element of drama. Students are asked to do the tests themselves rather than watching someone else and are required to show their results to their demonstrator.

Experimental investigations
This term is used to cover a wide variety of teaching methods which foster deep approaches to study by encouraging students to take personal initiative in the performance of the exercise. This might range from experimental design, choice of variables for investigation, choice of materials or methods, choice of methods of data analysis, through to choice of the problem for investigation. The investigation would usually be limited in time and scope and would not qualify as a project. Thus, it might be an extension of a controlled exercise which appealed to the student, or a variation of a well-known theme or method. Experimental investigations can be more or less structured – and often this means shorter or longer.
Structured investigations retain teacher control of materials or methods whilst giving students an opportunity for enquiry. Unstructured investigations retain teacher control of the aim but allow students to plan the materials and methods. In practice, experienced teachers can do much to anticipate students’ needs in the laboratory and avoid situations where unforeseen or unreasonable demands are placed on the technical support system.

**Advantages of investigations**
The first is the opportunity to allow students to practice skills of scientific enquiry, such as planning part or all of an experiment, whilst the second is the provision of a good motivational context. The two are linked: planning requires students to invest some personal initiative, and a sense of ownership and initiative is likely to be motivating. In the laboratory setting, it would seem that independent learning, project work, and experimental investigations share the qualities of independence and student motivation, but with decreasing freedom for independent learning.

Interviews with students show that they are very aware of the freedom for independence and of its effects on their motivation: the key to running successful investigations with junior students is not to throw them in from the deep end but to help them proceed from an adequate base of knowledge and skills (what Vygotsky calls their zone of proximal development – see ‘Teaching Engineering’). The idea of learning cycles is well described in the literature (e.g., Atkin & Karplus, 1963) and is further discussed in Boud et al, (1989).

**Disadvantages of investigations**
Why are controlled exercises retained as traditional fare? When do the disadvantages of investigations outweigh the advantages? Costenson and Lawson (1986) interviewed teachers and proffered a list of the top 10 teacher perceptions which have prevented the introduction of enquiry-oriented curricula into junior courses, or have resulted in this type of curriculum being discarded. Any faculty member introducing an investigative approach in undergraduate laboratory work might take note of which of these views they have heard expressed by colleagues.

1. Requires too much time and energy;
2. Too slow;
3. Required reading is too difficult;
4. Risk is too high;
5. Tracking – only the best students can cope;
6. Student immaturity;
7. Teaching habits are too ingrained;
8. Sequential material is a management problem;
9. Teacher discomfort with perceived loss of control;
10. Too expensive.

The issues at the heart of this worry list need to be seriously addressed although sometimes such views are based more on perceived threat, prejudice or conservatism rather than rationality and evidence. Two important factors in improving the successful running and institutionalisation of a programme of investigations are teamwork and staff development.

Example of an investigation
As an example of an experimental investigation, this one allows for more investigation than the controlled exercises discussed above, but is still on the same topic – how do polymers behave under different conditions? In this investigation, the students are given a series of different polymers, a few different testing apparatus and temperature controlling devices. The students are then asked to design an experiment which will explore the viscoelastic properties of polymers. There are many different possibilities including producing a stress/strain plot at different strain rates or temperatures, or by exploring stress relaxation, and these possibilities use the same basic equipment as before. Each student then produces a different piece of work, there can be no copying and each feels as if they have done something useful. There is no right answer but a feeling of having discovered what the concept of viscoelasticity is all about. It can be related to a real life issue such as investigating the properties of a polymer for use in skis, which need to be used at different strain rates and temperatures.

Done as a structured investigation, the students are given ready-made test pieces from which they select the polymer and decide on the test conditions. As an unstructured investigation, students decide what test pieces are required and either make them themselves or ask the workshop staff to prepare them. They decide on the test conditions and plan accordingly.
Project work
Projects are major pieces of work which are intended to simulate elements of real-life research and development activities. It is usually necessary to devote significant periods of time to projects, likely to be from a few weeks to a semester or even one or two years of an undergraduate course. Project strategies are devised whereby students can apply prior knowledge to new problems and, in doing so, to integrate various manual, technical, and enquiry skills in one coherent activity. Important characteristics are that the research problem must be a new one (where the student’s experimental work and results could be seen as a genuine attempt to contribute to scientific knowledge) and that the student carries out the work in a research setting where there would be access to research supervisors or team leaders (in an apprenticeship role, with a potential mentor).

Advantages of projects
Historically, participation in research projects was the common mode of students working in science courses, but concerns of cost and convenience gradually led to the reservation of research projects for postgraduate students and the use of controlled exercises for undergraduates. However, since the mid-1970s, there has been a widespread return to the use of projects with undergraduates. This seems to be a recognition of the need for students to be involved in intrinsically interesting, personally involving activities which are true to the nature of a science discipline (Bliss, 1990; Bliss & Ogborn, 1977; Dowdeswell & Harris, 1979; Ogborn, 1977).

Benefits of project work are many. The learning is individualized and students are likely to find their project a unique experience. Students are encouraged to accept responsibility for a piece of work and to build up some commitment to the scientific endeavour; they get the satisfaction of working on a sustained task and the opportunity to enhance their oral and written communication skills.

Disadvantages of projects and improving them
Conceptually, the disadvantages of projects are few – they seem ideally suited to students enhancing their technical, enquiry, and many other skills within a holistic experience. Practically, projects can be risky. The initial choice of a problem may be misguided; practical problems can result in overruns of time, energy, and cost and the supervisory relationships may not work well. In short, with the scale of project work, there is great need for careful planning.
by staff to ensure that the experience is a worthwhile one for each student.

**Examples of project work**

While final year projects can draw on students’ earlier undergraduate experiences, projects can be usefully employed in any year. They can be used from first year on with a degree of freedom suitable to the students’ stage of preparation. An example is the projects which have been trialled with second year mechanical engineering students at the University of Sydney for the subject of ‘materials selection’. During these projects, amongst other things, the students learn about polymer properties referred to in the examples of controlled experiments and experimental investigations given above. In essence the project is similar to problem-based learning, where students are asked to solve a problem and by solving it they learn new facts and ways of thinking. Students in this case were asked to form materials selection teams working for a large engineering company. In their teams they were asked to choose a structural object and to decide on the best material from which to make it. They might choose a crash helmet or a sailing boat hull, for example. They have to back up their choice with real evidence, for example tensile tests relating the strength of the material to the load it must withstand, toughness tests which relate to the impact loads (e.g. hitting your head on the road!) to which the object will be subjected, etc. Students also need to know the latest cost of the material and of production.

Each student or group is therefore actually conducting the exercise which Materials technologists would do in an engineering company in order to select the best material for a particular application. Students write up a report to the company manager to see if their idea is acceptable. Based on the evidence they provide and their argument, backed up by literature, they are given the commission, or they get a good mark! The whole project lasts three to four sessions of 3 hours per session.

**Assessment of student laboratory work**

Before considering assessment for a laboratory class, teachers need to consider a set of aims and objectives for the lab and the subject overall which lead to desired outcomes in student learning. These will be the knowledge, skills and attitudes which you would like the student to demonstrate, rather than a series of facts. Once these have been established it is possible to design an
assessment scheme which will ensure that you are testing for those attributes. For example, it has been found that if an assessment task is to ‘write up the lab’ and no guidance is given, students are most likely to reproduce what they did (or possibly what last year’s students did!). They are unlikely to reflect on why they did the experiment and what they got out of it unless they receive specific prompts and guidance.

It should also be possible to use the assessment scheme that you devise as a way of both finding out what the students have learnt, and feeding back information to the students about how they are learning and how they might improve their learning. For example, showing reports written by previous students who approached their learning with understanding, or offering feedback on draft reports before final submission. You could go further by involving the students in the process of developing suitable criteria for assessment and in critiquing outcomes in relation to criteria.

Graham Gibbs, in ‘Dimensions of Quality’ (The Higher Education Academy, 2010), points out that students’ reports on their projects represent a huge pool of experimental data about what and how students learn at university. However most project reports are seen only by the student author and two markers, and are then shelved for a statutory minimum number of years before being discarded to make space for more! It would be a fascinating piece of educational research to mine these data for evidence of the development of learning and understanding in engineering students – but we do not know of anyone attempting this.

**How do you want to assess?**
Providing you have clear statements of the subject and course objectives and a clear indication of which objectives should be met in students’ lab work, your assessment can be directly linked to criteria. Criterion-referenced testing simply means being able to select valid objectives for laboratory work and being able to specify the criteria by which successful performance would be recognised. For example, objectives in the polymer lab investigation described earlier are as follows:

- Define the relevance of the structure/property relationship in polymers to materials selection;
- Demonstrate the ability to interact with a group;
Demonstrate an ability to select and perform appropriate tests, critically analyse results and recommend testing schedules for the selection of polymers.

For any objective, there is usually a choice of assessment methods, some of which are illustrated below:

- Self assessment and peer assessment;
- Written reports;
- Verbal reports;
- Design posters;
- Practical tests;
- Observations;
- Written tests;
- Portfolio assessment.

The use of a range of appropriately chosen assessments should help students to understand the assessable goals of the subject (ideally, these are the most important goals), encourage students to take a serious approach to their lab work, and be suitably rewarded. In general it is helpful to be sensitive to any gender or cultural influences that may make one type of assessment more accessible to one group than another, and to provide practice assessments where necessary.

**Example of a written report style assessment**

An example of a written report with a difference is a case where students were asked to produce a user’s guide for a materials selection lab class. The guide provides results of the experiments performed in the lab, together with data from references. Having tested the mechanical properties of a series of polymers or metals, etc, students create a user-friendly guide giving values of modulus, ultimate tensile strength, examples of stress/strain behaviour, etc., which they have measured or collated. This helps students to realise the application of such a lab exercise and the student may refer to the guide in years to come to give a ball park figure for data. A material may then be selected for further analysis for a particular design, based only on this preliminary data.

**Discouraging fraudulent practices**

Anecdotes suggest that fudging of laboratory assessments is very common (Editor’s note: I did it!). An important point is that almost
all of this fudging occurs in controlled exercises – much less occurs in investigations and projects. It is as though fudging is a part of a certain culture where students take no ownership in their work and where matching a pre-ordained right answer is more important than anything else. Below is a series of hints on discouraging fraudulent practice:

- Take action to reduce student overload. Limit the range of goals for laboratory exercises;
- Reduce the emphasis on routine reports. Reduce the emphasis on right answers and increase the call for discussion and insight;
- Select an appropriate range of planning, technical skills and reporting to be done under exam conditions;
- Cut the number of written reports required. Select carefully those exercises which will be assessed by report;
- Allow student choice in the exercises to be assessed. They could choose the most stimulating, the most challenging, the one where they made the greatest personal contribution, etc;
- Discourage alienation. Avoid controlled exercises where possible. If retaining controlled exercises, find some way of making them a vivid experience for students;
- Encourage a sense of ownership and identification by favouring investigations and projects where possible. Allow reasonable choices of exercises to be undertaken;
- Set the lab work in a context where students can have some sense of identification and can see a clear vocational link or link to future course work;
- Introduce a log book system where students must record the day’s results in a permanent form, available for inspection, before taking them away from the lab. Require that these results be addressed in any write up;
- Negotiate with students the special criteria for each report used;
- Ask students to compare critically their results with those of other students, or with certain literature;
- Increase the emphasis on ‘own’ work;
- Include in the programme a discussion on issues in scientific ethics, perhaps with consideration of some of the more famous cases of scientific fraud – where possible include fraud cases from a diversity of cultures and eras;
Emphasise the value to one’s learning of finding what was different (‘went wrong’?) when the answer didn’t match the theory. This could include a discussion of serendipity in science, considering a range from more minor examples to those recognised and rewarded by a Nobel Prize;

As far as possible any assessment should be based on a topic different from that of the year or two before. This need not militate against students learning from the past. For example, if there is something a little unusual for students, such as their first encounter with posters, you may wish to display the posters from past years and discuss explicitly different ways in which a poster can be effective. However, to discourage copying, ensure that the new poster addresses a new topic;

In group assessment, identify the contribution made by individuals. Include further assessment of the project in a written or oral examination;

Try a portfolio system showing each student’s own profile.

Teaching in the lab: delivery of the lab class

Often the person ‘demonstrating’ the lab class is not the same as the lecturer or designer of the lab. The following issues specifically relate to the person actually teaching in the lab session itself.

Potential issues

Knowledge base: Questions known to concern demonstrators are as follows:

- How do we integrate the learning from their lectures into the lab?
- How do we know what is expected of me before, during and after the lab; what should we know?
- What if the students haven’t been to lectures or lack the fundamentals?

Student learning

- It is difficult to think about student learning when we get bogged down with technicalities;
- How do we help students to learn without it being another mini lecture?
Student respect

- How do we deal with bad student behaviour?
- How do we gain their respect so they do as we say?

Knowledge base

Showing expertise

- Being on top of the subject matter;
- Being well prepared for the lab;
- Being familiar with the ideas of the subject, the design of experiments, the use of equipment;
- Making it clear what has to be done and understood and why;
- Making clear explanations about the ideas, material, and activities;
- Using assessment methods which are valid and reliable;
- Giving students prompt and high quality feedback on their work.

Meeting students where they are in their learning

- Find out where the students should be and where they are in their learning of this topic;
- Supervising students closely enough to recognize those having difficulties with the concepts on which the laboratory exercises are based;
- Checkout understanding;
- Showing encouragement and empathy;
- Giving students positive feedback and encouraging them to note their own achievements;
- Providing adequate opportunities for students to practice their skills and to receive precise feedback.

Student learning

Fostering student independence and growth

- Supporting students when they are in high challenge situations;
- Encouraging active participation by students;
- Avoiding having them stand around in an observational capacity in the lab;
Enhancing student learning

- Emphasizing critical thinking, problem-solving, aspects of scientific enquiry, and other intellectual activities which require the students to think;
- Encouraging students to focus on the integration of the practical exercises with the learning of material taught in other components of the course;
- Encouraging students to have a lively understanding of the interplay of theory and methodology in the laboratory.

Facilitating not lecturing

- Trying to avoid telling students the facts but helping them to find them out themselves by asking questions etc. This is probably the most difficult thing for a demonstrator to learn, and is the single biggest reason why the training of ‘demonstrators’ is essential. We should find a better word than ‘demonstrator’ too; perhaps ‘laboratory advisor’ or similar would be better.

Student Respect
Respecting students

- Demonstrating respect for each student as a person;
- Valuing diversity;
- Demonstrating a positive attitude;
- Teaching free of discrimination or stereotyping of students because of gender or ethnicity;
- Monitoring student groupings in the lab and the nature of classroom interactions to bring out the best in each student.

Sharing enthusiasm and making laboratory work an enjoyable experience for students

- Finding ways for love of the subject to come across to students;
- Helping make the students’ work relevant, interesting, stimulating and challenging;
- Being friendly, helpful and available to the students;
• Using humour and other techniques for fostering an enjoyable, relaxed, and non-stressful atmosphere in the laboratory;
• Being a good role model for students.

Finally, you might consider the problems a student has when first entering a laboratory. She or he probably faces unfamiliar equipment, designed for an unfamiliar task, and may spend a significant amount of time working out what each item is for, and what the activity entails. A useful aid is a computer-based ‘Pre-Lab’ exercise in which the student can run through the experiment in virtual form before entering the real laboratory. We have found this very useful at Liverpool and for many laboratory exercises insist that the pre-lab is completed (and a certificate produced) before entry to the laboratory is allowed. However you do need some resource (or some time) to write the simulation.

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Tutoring

Graham Gibbs has reported (‘Dimensions of Quality’, Higher Education Academy, 2010) that one of the most useful measures of quality in higher education is the size of the smallest group in which the student learns. Large classes are in themselves not conducive to learning. Tutoring therefore has great potential to enhance the experience of each student. Adam Mannis and Shanaka Katuwawala, in the original booklet [http://www.materials.ac.uk/guides/tutoring.asp] pointed out that this is made easier by the relatively small size of typical classes in Materials.

It is clear that with small class sizes the scope for teaching in small groups, or tutorials, is much higher than in other engineering subject areas. It is also well known that small group teaching is good for dealing with learning difficulties associated with multiple learning styles, diverse cultural and academic backgrounds, as well as motivation levels.

What is meant by a tutorial?

In this text we will use 'tutorial' to mean a smaller group of students than the full class. In practice this can mean anything from a single student to a group of perhaps twenty students, depending on the context. What you can achieve with such a group will depend strongly on the size of the group. In many cases small is indeed beautiful, but there are activities which require the multiple inputs and perspectives of five or six people.

Why use tutorials in teaching?

Addressing student diversity in tutorials

When we consider our student population, we need to be aware of and take account of differences in expectations, in academic ability, in age and maturity, in work-related experience, in mathematical and physical science background knowledge and skill, in personality, spatial ability, cognitive type, learning style, cultural and language background, as well as gender. We need to be aware of what approach students take, because of their different experiences and filters of perception (Marton and Booth, 1997).
We should also think about the accessibility of various tutoring approaches if disabled students are involved. Parker (1999) discusses some important issues relating to visually-impaired students, deaf and hard of hearing students, students with medical conditions and students with learning difficulties (including dyslexia). All of these disabilities may prevent students from learning in certain conditions and rooms.

**Addressing student employability in tutorials**

Tutorials represent a very important opportunity for encouraging students to think – to compare ideas, give expressions to their understanding of a subject, to help each other share and compare ideas, to encourage active learning and the exchange of ideas, and to evaluate and develop personal and professional values. Additionally, tutorials can be used to help students acquire and practice the important professional skills of team working, leadership and communication skills. Through their active involvement, students can be encouraged to monitor their own learning and gain a degree of self-direction.

Materials Scientists, like all Engineers, will usually find themselves working in teams, solving problems. Analysis, critique, assessment of selection criteria, redefining problems or problem finding, as well as creative thinking are all essential elements of their jobs. Students need to develop these skills as well as enhance their ability to communicate their creative ideas and their finished work or innovation to an audience (customer, designer, etc.) (Dewulf and Baillie, 1999).

**Where are tutorials used in teaching?**

**Academic tutorials – subject oriented**

The academic tutorial ‘is concerned with the development of the student’s powers of thought’ (Jacques, 1991) within a subject or course. It is, in general, aimed at one to six students – in a one-to-one tutorial the tutor may focus completely on work completed by the student. In some situations, classwork sessions of between twenty to thirty students are also called tutorials, as their main aim is interaction with students, and for the students to work and think during the session.
Skills development
Some tutorials or small group work is designed to promote certain personal transferable or professional ‘key’ skills. Schemes are increasingly introduced into degree programmes to improve students’ skills in teamwork, communication (oral and written), leadership, creativity, etc (Dewulf and Baillie, 1999). These might be ‘add on’ sessions with the whole class, in small groups, or as part of the academic or personal tutoring system. They might also be integrated throughout the degree programme.

Specific attempts are made in the first year in many universities for students to learn how to learn (Baillie, 1999). There has been a move in recent years away from the ‘study skills’ approach of telling students how to study, and towards the idea of helping students develop a responsibility towards learning which motivates them to understand rather than reproduce (deep rather than surface approach) (Ramsden, 1992).

Personal tutorials or mentoring
In most UK universities academic staff are allocated one or more personal tutees who they are asked to ‘monitor’ during their time of study. With student-staff ratios exceeding 20 in many departments, it is clear that each tutor must have on average 20 or more tutees, spread across the 3 or 4 years of the programme. The operation of ‘personal tutorials’ is very ad-hoc, with some academics taking their role more seriously than others. Some personal tutors see their students once every one or two weeks at least for the first year. Some do not timetable sessions for their tutees, but students at least know they are there. This can be less than satisfactory in some instances where lack of support was found to be the main cause of student dropout. Personal tutors are rarely trained for their job, and often neither student nor lecturer fully understands the boundaries of their role. It is obvious that the tutor is not a professional ‘counsellor’, and yet this is often the term used to describe their role.

Who can teach tutorials?

Staff tutors
In the UK it is common for academic staff to take tutorials, both academic and personal. In some universities lecturers are trained in small group teaching techniques as part of their initial induction, but fewer are trained in personal tutoring / mentoring skills. Senior tutors oversee the system in many UK universities, and they are
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responsible for the personal or sometimes the academic tutorial schemes of departments. Therefore the effectiveness of tutorials in different departments often relies on the senior tutor’s capabilities and responsibility.

**Peer tutors**

Peer tutoring schemes have been successfully implemented in many universities worldwide to promote student learning (Magin and Churches, 1995). Peer tutors help younger students to learn by holding group sessions in which specific topics are discussed. The aim of the scheme is not to provide textbook answers to set problems or even to provide formal supplementary teaching, rather it is the peer tutor’s role to act as a focus for the group and thereby make it work for itself. More specifically, the group provides a supportive environment for new students to:

- test their understanding of difficult concepts introduced in lectures;
- gain confidence in dealing with the volume of and complexity of material;
- use the staff-run tutorial system effectively;
- take more responsibility for their own learning;
- participate in co-operative problem-solving methods;
- develop a deeper approach to learning.

In the Department of Materials at Imperial College London, a peer tutoring scheme was established in October 1997 for the first year crystallography students, focused on the learning of crystallography (Baillie and Grimes 1999). This proved very popular over the years with at least 60% voluntary attendance.

**Tutor training**

In many universities the training of staff is a compulsory part of their induction. Small group teaching may or may not be included in the workshops that staff have to attend as part of their training. However, mid-career staff may never have been trained in small group techniques and have little understanding of their role and function, nor any experience of facilitating rather than teaching or lecturing. Mentors and senior tutors are rarely trained. Postgraduate tutors are less often trained. Peer tutors are always trained, and this is an imperative and very effective part of the peer tutoring schemes that are run. The training is often seen as so useful that some lecturers could also profit from such a course.
Interaction, both learner-to-learner and learner-to-tutor, is another powerful method of ensuring learners maintain an appropriate pace, and judicious intervention by tutors can help motivate and encourage learners to keep going. The role of the tutor in distance learning is a subject in its own right and we recommend that you consult one of the sources listed under ‘Further reading’ if you wish to pursue this further.

How can tutorials be run effectively?

Motivating students of mixed abilities and backgrounds

a. Key issues

‘Materials for Engineers’ classes often consist of students of mixed abilities and backgrounds, with and without chemistry or maths. The class may even contain students from different disciplines or branches of Engineering. Tutors will have to cover the same core Materials information – so how can they deal with this, and motivate the students?

- Tutors can learn from motivation literature about what to do with students in groups, to help them realise that Materials is not just something to be swallowed whole and regurgitated in an exam i.e. staff should help develop a deep approach to learning in students;
- Tutors could teach general principles in lectures and apply these to different contexts (e.g. different problems for different branches of Engineering) in associated tutorials;
- It is important that tutors understand and appreciate how to teach to different backgrounds; e.g. so as not to lose the well-prepared students through boredom, and the less experienced ones by moving too fast. School teachers are trained to do this as a matter of routine, calling it ‘differentiation’ or ‘personalized learning’, but university teachers have been very slow to appreciate the need for such approaches;
- Tutors can help students to appreciate Materials as a subject in its own right and not the poor relation of other Engineering disciplines, or as something else like Chemistry.
b. Increasing student motivation for studying Materials

Engineers often see Materials as a subsidiary subject. Only when failures occur does the importance of materials selection become apparent. What can tutors do to encourage motivation for studying Materials?

1. *Tutors need to appreciate where the first year student is ‘at’*:
   - They should consider the fairly narrow zone in which learning can be effective for each student (look up ‘Vygotsky’ in the parent book);
   - They need to adjust to the diverse intellectual levels and styles of learning of their students;
   - Often, they are not thinking of what the student is receiving.

2. *Students need to have the fundamentals of Materials in place very early on, and the cross disciplinary aspects of Materials need emphasizing*:
   - Stress the importance of concepts rather than details;
   - Encourage linking of concepts across modules, so curriculum design is extremely important.

3. *Tutors must continually emphasize the relevance of studying Materials to students*:
   - Highlight the importance of Materials to society;
   - Continually impress on students, what is the point of doing this?;
   - Indicate that materials selection, manufacture and design challenge is intrinsically rewarding;
   - Stress the wide range of career opportunities that the study of Materials affords;
   - Use graduate profiles to remind students that the course is worthwhile.

4. *Giving realistic feedback is crucial to motivating students*:
   - A good personal tutor system can make a significant contribution here;
   - Use assessment to check for understanding not rote learning;
5. *Interactive teaching helps increase motivation:*

- Introduce fun things to do and hand out real examples of Materials to students;
- Group work can help motivate students, as can hands-on lab experiences.

**Implementing teaching and learning innovations for better student understanding**

Key issues include: How do tutors stimulate students to develop a ‘feel’ for a material and a mental picture of how a material behaves? What teaching and learning innovations help address the changing skills base of Materials Science and Engineering students? There are no single straightforward answers to these questions but you might bear in mind:

- It is very important that tutors help students gain an appreciation of materials, especially when they don’t get to feel the materials (so do keep lots of components and samples of materials in your office!);
- Tutors should ensure that there is an adequate balance of theory and practice, and that students see subject relevance;
- Tutors need to carefully consider assessment to make sure that Materials is not assessed by memory-only exam-style questions, which can be the case for relatively less mathematical subjects. Even in the first year, concept-based questions are necessary.

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Learning at a Distance

Mark Endean, of the Open University, points out in the original Guide, that more and more students are finding themselves learning ‘at a distance’, even in institutions that are ostensibly single-mode face-to-face (f2f) teaching establishments. So, whether or not we see ourselves as engaged in the business of distance education, all academics need to have a basic understanding of the requirements of distance learners and some idea of how best to support them while they attempt to learn.

What is here?

This section is a distillation of the essential elements of distance education and a succinct guide to how to produce effective distance learning materials. It is not a course in developing full-blown distance learning courses. But the underlying rules, tips and tricks are precisely those that go in to the best examples of such courses. Many of them will also benefit f2f learners if applied with imagination.

There is a plethora of excellent guides to the production and presentation of distance learning materials. A number of these are listed at the end and if you are serious about developing distance learning modules, you are strongly recommended to consult them. The best we can hope to do here is to provide a number of aides memoires and attempt to encapsulate some of the accepted wisdom on distance learning.

If you are hoping to develop a distance learning module for yourself, you would be wise to follow the guidelines provided here. But all such activities are experimental so have a go, enlist the learners in the experiment and see what happens!

Definitions and Concepts

‘Open learning’, ‘distance learning’, or ‘open and distance learning’?

Open learners study in their own time and at their own pace (within reason – more on this later). Distance learners are physically and/or temporally remote from each other and their ‘teachers’. So each type of learner has their own needs. Try this:
How many different ways can you think of connecting distance learners to their ‘learning community’?  
Which of these could not be used for open learners without compromising their ‘openness’ and why?

So you see, open learners need not be distant and distance learning need not be open.

**Open and distance learning** (ODL) is the term coined to cover the common ground between both types of learner. You need to decide where on each of the scales of openness and distance you want or expect your learners to be.

**Learner support**

One of the key questions to address as a provider of ODL is the extent and manner of support you will be offering to learners. All learners need access to some kind of ‘tutor’ to help guide them through the sticky patches (see previous section for some comments on the role of the tutor). The range of possibilities extends from old-fashioned ‘correspondence tuition’ to regular f2f meetings and includes student/student peer support. Many factors combine to influence what level of support is appropriate, ranging from the geographical distribution of learners to the cost of providing a given level of service. But support there must be if learners are to complete in any numbers.

**E-learning and on-line learning**

The advent of almost universal domestic access to the Internet has dramatically altered educational providers’ views of ODL. The concept of ‘putting the course notes on the World Wide Web’ and thereby creating a course has, thankfully, now largely been discredited. But there remains the feeling that anyone with a computer is a potential ‘e-learner’ – for which read ‘sales prospect’. We have attempted in this guide to adopt an approach that is independent of the medium of delivery or presentation of the

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2 This is what we would suggest, in no particular order: telephone; email; correspondence; webchat; computer-mediated conference; video-conference; audio and video media.

3 The synchronous methods – telephone; webchat; video-conference – are unsuitable as they tie the learner to a time and place. Only the asynchronous communication methods could be used for true open learners.
learning materials. The principles of good ODL apply just as much to e-learning as traditional approaches, if not more so. The computer provides a great opportunity to do some things better (or at least differently). But it presents many pitfalls to the obsessive technophile.

**Effective ODL**

According to Rowntree (1994) among others, to be effective, ODL materials have to be:

- Purposeful;
- Structured;
- Paced.

To these, we would add a fourth characteristic:

- Engaging.

**Purpose**

Why are you reading this? Stop and write down at least two plausible reasons. (I'm not going to provide any answers to this – the reasons must be your own.)

Was it clear enough at the beginning that your needs were likely to be satisfied by what you would find here? The point is a general one: it's not enough simply to have a clear sense of purpose when you prepare ODL materials, you also have to communicate that clearly to the learner. So how do we define and communicate purpose?

The most obvious definition of purpose for a learning package is what the learner will be able to do at the end – the current term is 'learning outcomes' but historically the word 'objectives' has also been widely used. The most successful ODL materials have always had clear statements of outcomes couched in terms that are unambiguous. For me, the test of a good learning outcome is whether the learner can point to some specific evidence that they have achieved it. Try this:

- How might you demonstrate that you have achieved the following outcome?
Having completed this module you should be able to understand the significance of van der Waals’ bonding in determining the behaviour of polymers close to their glass transition temperature.\(^4\)

Of course to demonstrate any learning outcome you have to do something. So why not rewrite the outcome in terms of what the learner should be able to do? It takes a little more thought but can be much more informative for the learner. Linking outcomes to some form of assessment reinforces the learner’s sense of purpose.

*Test each of your outcome statements by asking yourself always: ‘What evidence could we produce to show that we could now do that?’*

Most of us have come to terms with living in an ‘outcomes-focused’ learning environment. Everything we do has to be circumscribed by one or more sets of learning outcomes; the two principal reference points for the Materials Science and Engineering community are the ‘benchmark statements’ produced by the Quality Assurance Agency (Quality Assurance Agency, 2008 and 2010, and the ‘output standards’ developed by the Engineering Professors Council, 2006). It takes a little creativity to turn a benchmark statement into a learning outcome statement, as a further look at the extracts cited at the beginning of this guide will illustrate. But a well-constrained learning module lends itself quite easily to such descriptions. We recommend the following approach:

1. Trawl through the appropriate benchmark statements for each of the levels of attainment and decide which statements apply to your module and at what level;

2. Collect together the statements that apply under appropriate headings (note that the Engineering benchmark statements are not categorized in exactly the same way as those for Materials, so if you choose to use statements from both subjects you will need to invent a compromise);

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\(^4\) My suggestion is that you would have to *describe* the nature of van der Waals’ bonding and its relationship to primary bonding, and *explain* how the thermal energy in the system can be sufficient to overcome the effects of vdW forces above Tg.
3. Particularize each statement to your module by adding information from the module.

For example, suppose you were planning a short ODL module on corrosion at a relatively advanced level (assuming some prior knowledge of the subject). The relevant benchmark statements work as follows:

The benchmark statements for Materials (Quality Assurance Agency, 2002) suggests under ‘Materials related knowledge and skills’ that:

... Materials graduates will have ... some familiarity with relevant concepts associated with ... degradation / durability of materials – effect of liquid and gaseous environments on the performance of different material types.

Given the level of the module, you might be pitching the outcomes at ‘Attainment level B’ according to the benchmarking document, which states that:

New knowledge is readily acquired ... Routine calculations, explanations, interpretations and analysis are executed accurately. Understanding of relevant facts and techniques is good.

A relevant benchmark statement for Engineering (Quality Assurance Agency, 2000) was to be found under the heading of ‘Knowledge and understanding’ in the ‘Design’ category. At a ‘good’ attainment level, graduates are expected to have:

... knowledge and understanding of the characteristics of engineering materials and components.

Now write out what you think would be an appropriate learning outcome for this module on corrosion, recognizing the benchmark statements for both Materials and Engineering. You might need to leave some gaps in the outcome statement to take account of the actual content of the module.\(^5\)

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\(^5\) I would propose something like this:

Can describe and explain the effects of [specified types of corrosive environments] on [particular types of materials] and can use the associated
Once you have a set of learning outcomes, you need to ensure that the module itself adequately supports those outcomes, and is designed in such a way that learners collect evidence that they have achieved them as they study.

**Structure**

The structure of a learning module is of paramount importance in maintaining a learner’s interest. Just as with purpose, the structure must be clear to the learners and this will allow them to exert some control over how they learn. Distance learners can feel extremely isolated and a feeling of control is a great boost to self confidence.

There are a number of ways of structuring ODL materials, each of which can be equally effective but each has its distinct advantages and disadvantages. The following brief list encompasses most options:

- Teaching ‘narratives’;
- Textbooks and commentary;
- Action guides and resources.

Think always in terms of a **narrative**. People find it easiest to follow something that has a beginning, a middle and an end – something akin to a ‘learning journey’. The narrative does not have to reside explicitly within the learning resources. It can be constructed by the learner themselves, under your guidance or in collaboration with other learners. The choice of structure you adopt is crucial to deciding how to provide a narrative but a random collection of ‘learning objectives’ is not likely to motivate the learner.

In the case of **teaching narratives**, you are going to have to construct the learning materials effectively from scratch. You should not underestimate the commitment this requires and the time and trouble you will have to take.

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*knowledge to suggest and justify improvements to given designs in order to mitigate or avoid problems associated with materials degradation.*

It’s quite wordy so this one outcome could well be broken down into several components.
Continuing with the subject of corrosion, one way of structuring a linear teaching narrative might be (don't take this too literally):

1. **Introduction**: explaining the importance of understanding corrosion by means of a few examples and setting the limits to what the module will cover.
2. **The physical chemistry of corrosion**: introducing/revising the thermodynamic and kinetic factors driving corrosion.
3. **Materials and corrosion**: looking at how materials interact chemically with their environments resulting in corrosion.
4. **Case studies in corrosion**: showing how the information provided in the module so far can be used to explain and avoid problems of corrosion in the real world.

Having written such a text, you must ensure that it is reviewed for accuracy and edited for sense and style by other colleagues. Of course this will add time to its production, but will more than repay the time cost in increased effectiveness.

An alternative way of providing such a learning package is to use existing published texts to cover the same ground. You could keep the same order of material that we have suggested above but this time provide a specified list of readings under each of the headings (with the possible exception of the introduction). Such readings, however, are likely to be crucially deficient in many of the key attributes of ODL materials that we have listed in previous and subsequent sections. So you can provide them in a narrative commentary. This is your opportunity, of course, to criticize the established view on the subject. Mostly, though, you need to think about how to assist the learner actually to learn from the given texts by incorporating appropriate interaction.

A different approach is to turn the narrative on its head. Given that effective learning involves doing things, a good way of generating learner-focused learning materials is to set the learners one or more tasks and guide them to the sources of information they need to complete the task. Here the learner will be providing much of the narrative for themselves and this approach requires a significantly higher level of sophistication from both you and the learner.
Such a learning module could consist of:

1. One or more case histories describing situations where corrosion caused a problem;
2. A report outline that learners are expected to complete about each case history and submit for assessment;
3. A reading list containing all the key information;
4. A discussion forum where learners can work together to identify and pursue the key aspects of the problem, effectively constructing their own narrative.

The last approach highlights the fact that the structure you adopt can depend as much on the abilities and stage of development of the learners as on what you are hoping to achieve. So you might consider a progression from purpose-written narratives at Level 1 to more of a resource-based learning approach at Level 3.

Race (1992) is worth consulting for more ideas and suggestions.

Pacing

Have you read to this point without stopping? Or did you stop at some point and then start again some time later? Distance learners need to know how much time to spend on a given learning package, when it is permissible to take a break in their studies and when they need to pick them up again.

I mentioned earlier that open learners study at their own pace. Those experienced in ODL will know that completely open-ended study is rarely effective. Most learners will lose momentum at some stage and, without a truly pressing need to continue, will rarely pick things up again. Mostly the pressing need is some form of assessment, so here we have one of the main techniques for pacing learners – deadlines!

Assessment deadlines can be published in a study calendar which also provides you with an opportunity to suggest the overall pace of study you expect from the learner. The pace itself should be a balance between what you think is reasonable to expect from the learner (given that they are studying at a distance and in conjunction with other activities) and how the particular learning module ties in with other modules in the programme.
Interaction, both learner-to-learner and learner-to-tutor, is another powerful method of ensuring learners maintain an appropriate pace, and judicious intervention by tutors can help motivate and encourage learners to keep going. The role of the tutor in distance learning is a subject in its own right and we recommend you consult one of the sources listed under ‘Further information’ if you wish to pursue this further.

Engagement

Do you want to know what comes next? Why? Is it really that important to you or have we managed to excite your interest despite more pressing demands on your time?

Look back over the previous section of this booklet and identify at least three devices we have used to engage your interest. Which do you think is most important and why? 6

There really is little point producing learning materials that don’t engage the learners in the process of learning. As academics we tend to present information in just about as dull a fashion as is imaginable. But think about it from a learner’s perspective. Would they rather be working through your stuff or doing the ironing? We can think of many occasions when the ironing seemed infinitely preferable. And, unlike the captive audience in a lecture theatre, there is actually nothing stopping the distance learner getting up and walking away when they lose interest. So you have to put some serious thought into engaging and motivating the learner.

Some of the rules of engagement in distance learning are not so obvious, so here are a few notes that you might find helpful.

- You are addressing the learner as an individual so do so directly. You should be ‘I’; the learner should be ‘you’ (singular). The pronoun ‘we’ should be reserved

6 I think we have:
- engaged you in a ‘conversation’;
- given you things to do;
- provided a clear structure;
- set out some outcomes that are relevant to your needs.
In my opinion, this is the order of importance of these four devices. If learners are involved in the process, everything else follows on.
exclusively for those occasions where you want to include both you and the learner;

- You should avoid the passive wherever possible as it distances the learner from what is going on. You can generally do so without resorting to the impersonal ‘we’ by making what you are discussing the subject of the sentence;

- Use humour sparingly;

- Give some thought to the diversity of your learners. This should not be a manifestation of political correctness. But they won’t all share your cultural heritage so you should be careful of references which include assumptions about gender, race, language, history and so on. If the learner misses the point for these reasons you might just as well not have written it.

A note about media

As we stated earlier I’ve used an approach that has avoided discussing the medium in which the learning module might be presented. The fashion over the last decade in ODL has been a steady move towards electronic media (stand-alone and networked). But as the developer of an ODL module you should think carefully about the appropriateness of the media you intend to use.

Write down two advantages and two disadvantages to presenting study materials on a computer screen rather than sending learners traditional materials such as print and cassette.\(^7\)

\(^7\) Presenting materials ‘electronically’ can:

- virtually eliminate the delays inherent in printing and delivery of conventional materials;

- provide built-in ‘multimedia’ capabilities where text, audio, video, www etc. can be integrated almost seamlessly into a single ‘document’;

- provide effective updating routes for frequently-changing information or to deal with errors etc.

They can also:

- tie learners to a computer, which is at best an awkward thing to carry around compared to a book, notebook, smartphone etc.;

- go wrong with disastrous consequences for the distance learner;

- transfer the costs of printing to the learner.
The actual choice of the mix of media should be led by a combination of the learner’s needs and your own. The effectiveness of the learning experience hinges more on aspects of purpose, structure, pacing and engagement than on precisely which media you choose.

Any discussion of media would be incomplete without some reference to current legislation on disability. The best advice on this must be to consult the experts as to what is practicable at as early a stage as possible. We have included a checklist point on this in the template that follows.

A template for an ODL module

Finally we offer up a template for you to use to focus your thinking about the ODL module you plan to develop. If you allocate time to filling in such a template, not only will you be well on your way to finalizing the module but you will also have a document you can discuss with both colleagues and potential learners.

- What is the title of the module?
- Of what (if any) larger course or programme is it a part?
- Who is the intended audience?
- Construct one or two appropriate assessment tasks for the module.
- How will learners’ performance on the module be assessed?
- What are the intended learning outcomes?
- How will you obtain or produce these resources?
- What learning activities will you ask learners to do as they study the module?
- What issues arise for learners with particular learning difficulties?
- What support, tutoring and feedback will you provide?
- What resources will you provide to learners studying the module?

Further information

Courses
The National Extension College [http://www.nec.ac.uk] offers courses in online tutoring
The Open University [http://www.open.ac.uk] offers postgraduate courses in Open and Distance Education

**Organizations**

BAOL, The British Accredited Open Learning [http://www.baol.co.uk] is a forum for UK providers of ODL, mostly from the private sector

EADL, The European Association for Distance Learning [http://www.eadl.org] offers a Europe-wide forum for ODL providers

EADTU, The European Association of Distance Teaching Universities [http://www.eadtu.nl] concentrates on HE providers in the public sector

ICDL, The International Centre for Distance Learning [http://icdl.open.ac.uk] maintains a vast database of information about all aspects of ODL

ICDE, The International Council for Open and Distance Education [http://www.icde.org] is a global organization supporting ODL providers that sponsors a biennial World Conference which attracts thousands of delegates from many different countries.

ODL QC (Open and Distance Learning Quality Council) [http://www.odlqc.org.uk] is an accrediting organization for ODL providers, mostly below HE level and in the private sector. Their Quality Standards [http://www.odlqc.org.uk/standard.htm] are a model of their kind.
Part 3: How to assess the students’ learning

Lewis Elton, the author of the original booklet on assessment [http://www.materials.ac.uk/guides/assessing.asp] wrote: ‘Materials education as a discipline, whether in Materials Science or Engineering, is concerned with the development of both knowledge and skills. It may be concerned also with the development of attitudes, but assessment in that area is difficult’. In all of this it is no different from many other disciplines, but because of its position between the pure and applied sciences and its comparative novelty as a discipline, it may be easier to meet current needs and be innovative than might be the case in more established disciplines. In line with the well known dictum that ‘assessment drives the curriculum’, assessment in Materials education may therefore provide an unusually favourable opportunity to the innovator and iconoclast.

Assessment of knowledge may in principle be well understood, but much practice falls short of what is known as good practice, particularly in relation to the application to knowledge of the higher order academic skills, such as analysis, synthesis and evaluation. A brief account of aspects of good traditional practice is therefore given in the next section, which is adapted from the Appendix of Elton and Johnston (2002).

Assessment is of two kinds, usually referred to as ‘formative’ and ‘summative’; the purpose of the former being to help with learning, while that of the latter is to judge what has been learned. The conventionally accepted view is that the two must be kept separate, because they fulfill very different purposes and usually occur at very different times in a student’s course – although coursework assessment can have both formative and summative aspects. In principle, formative assessment is much the more important, since it aims to improve learning, while summative assessment merely verifies the learning that has been achieved. In practice, as students’ careers and future lives may be dependent on the outcome – they treat summative assessment more seriously and it is often very difficult for teachers to get their students to put effort into formative assessment. Knight (2002) has questioned the need for the complete separation of the two kinds of assessment in a way that will be seen as highly relevant to the matters treated later in this section.
Another, and very fundamental, dichotomy is that between two fundamentally very different forms of assessment. One, for which the technical term is positivist, makes the assumption that ‘truth’ (the inverted commas are to indicate that the concept of truth is not simple) is absolute and that assessment matches student performance against a previously established model response which exists in the minds of examiners. The other, for which the technical term is interpretivist, explicitly accepts that ‘truth’ is a social construct, i.e. ‘a matter of consensus among informed and sophisticated constructors’ (Guba and Lincoln 1989, p44), a consequence of which is that experienced examiners can agree on a student’s performance only after the performance has taken place. The word ‘experienced’ here is designed to ensure against the ‘anything goes’ phenomenon. In the past, most examining has taken place in a firmly positivist mode, but there has always been a notable exception to this rule – assessment in architecture and in art and design, where the famous ‘crit’ is firmly interpretivist. Materials Science and Engineering, with their strong claims to be creative subjects (see e.g. Dewulf and Baillie 1999), in which creativity is however reined in by the laws of science, may call for an assessment system that is in part positivist and in part interpretivist. This booklet will propose such a case. A similar case can be made for mathematics, which is inherently positivist, but where mathematical modelling – particularly in applied disciplines – might constitute an ideal topic for an interpretivist treatment.

A final dichotomy is that between process and product. There has been a strong demand from powerful bodies, such as the Quality Assurance Agency, that assessment should verify specified outcomes (i.e. products) and furthermore that these should be specified in advance. Educationists argue against this view, saying that:

- Learning can never be completely pre-specified, which introduces an interpretivist aspect into even the most positivist scheme; and
- It is often not possible to assess final learning outcomes, in which case only the process of learning can be assessed.

The second point is particularly important in connection with the development and assessment of higher level skills and abilities, which are much more closely associated with process than product.
Assessment: Setting Examination Questions

Knowledge is primarily assessed in formal examination papers in which students are asked to select a portion of the questions set, which are ostensibly of the same difficulty. As this type of paper can test knowledge only selectively, it should only be used if the knowledge being tested is of very minor importance and if the academic skills tested by the different questions are of comparable difficulty. A broadly speaking hierarchical scale of such skills (developed from the work of Bloom et al 1956) might be as follows:

- Basic knowledge – i.e. little more than memory work;
- Comprehension – e.g. simply rearranged knowledge;
- Application of knowledge – e.g. to practical problems;
- Analysis – e.g. relation to basic principles;
- Synthesis – e.g. bringing together relevant disparate considerations;
- Evaluation – i.e. judgmental treatment of knowledge, analysis and synthesis.

Clearly, basic knowledge should be treated comprehensively and not selectively, while the higher skills, which are concerned with academic skills applicable to the basic knowledge, can be exhibited with any basic knowledge. It is therefore reasonable that students should have a choice of knowledge base in which they demonstrate their academic skills. This leads to the idea of a structured examination paper, with progressively more choice (or of course to different types of papers for the different levels of the hierarchy). A structured paper might look as follows:

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Multiple choice questions (no choice)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehension</td>
<td>Short answer questions (limited choice)</td>
</tr>
<tr>
<td>Application</td>
<td>Essay or problem questions (considerable choice)</td>
</tr>
<tr>
<td>Analysis</td>
<td></td>
</tr>
<tr>
<td>Synthesis</td>
<td></td>
</tr>
<tr>
<td>Judgment</td>
<td></td>
</tr>
</tbody>
</table>
Formulating questions in this way implicitly raises the question of the learning objectives which are being tested. All too often, questions are formulated in terms of content, but questions of similar content may be asked at different skill levels in the above hierarchy, in which case the same type of learning is not tested. It is therefore vital to be clear about the learning objectives which are being tested, in terms of both content and skill level. And not only must the examiners be clear on this matter, but students must have been made explicitly aware of the importance of these levels.

Many examination questions are of the essay type and these present another difficulty. Essay questions normally contain an ‘operative’ word, such as:

- Define;
- Describe (or list);
- Analyse;
- Compare;
- Argue (or justify);
- Evaluate;
- Explain (or account for);
- Assess;
- Contrast;
- Critically examine.

Such operative words give an indication how the question is to be answered and they should have definite meanings, which are shared through previous preparation by teachers/examiners and students. Unfortunately this is rarely the case, the understanding being generally tacit for the teacher or examiner and for that reason not shared with the students. There is often no way of knowing whether this tacit understanding is the same for all examiners, and so only those students who happen to share the tacit understanding of a particular examiner are likely to do well. What is needed for a fair assessment is for that understanding to become explicit between teachers and students and for examiners to agree to it. Furthermore, it may be noted that perhaps the most common operational word, i.e. ‘discuss’, is not in the list, as it has too many different meanings in different circumstances, each one of which is better expressed by one of the words in the above list. Could it be that the popularity of this word in examination questions reflects the not uncommon attitude in examiners to deliberately be vague in a question, in order to see how students tackle it and then
match their responses to the examiner's preconceived perceptions, which are of course unknown to the examinees? And never, but never should an essay question take the form of literally a question, unless a straight 'yes' or 'no' is considered an adequate answer.

Finally, it is worth raising the issue of using computers in essay examinations. Students are now strongly encouraged to word process their coursework. Is it then right that they should have to return to pen and paper for their examinations? And if not, can the problems associated with bringing computers into examinations be overcome? There are at present no answers to these questions, but they are worth asking.

**Progressive Questions**

Questions which are in several parts, and in which information in the earlier parts helps in responding to the later ones, are common in the sciences. In such composite questions, the first part is often a pure memory question, the second part uses the information contained in the first part in solving a problem and the third part may similarly use it for a more theoretical question or, put differently, the level of learning objectives goes up as the question progresses. However, in such cases, the wording of the first part gives information on the later parts (e.g. what might be a good starting point for solving a particular problem) and thereby makes the later parts easier than they would have been, if the first part had been omitted. Since a most important aspect of problem solving lies in the identification of a suitable starting point, this may devalue the question as a test of problem solving skills. Furthermore, if such a question is now set in an open book examination, and the first part is omitted, as being purely memory work and therefore unsuitable for an open book question, then the problem part may have been made considerably harder by this omission – a fact that is often not appreciated.

**Questions with redundant or incomplete information**

A form of question which is at a deceptively high level of learning objective is one where the information provided may be too much, too little, or just right to solve the problem set in the question. Such a question introduces an element of uncertainty, which is normal in everyday life and therefore is well designed to test certain life skills.
Multiple Choice Questions (MCQs)
The perception that MCQs can test only for knowledge recall is doubly wrong: all MCQs test for recognition rather than recall, but they can test at all levels of the hierarchy. However, the higher the level to be tested, the more difficult is it to set good questions.

‘Quite generally, because multiple choice questions give no information concerning students’ thought processes, it is particularly important that they should be of a high professional standard’.

Examiners should not use MCQs unless they have been trained in their use, and this is true even if the MCQs are taken from professionally generated question banks.

Equal Opportunities Issues
This may be a good point to refer to equal opportunities issues. The following ought to be considered in connection with any questions set in an examination:

- Is there a race or gender bias in the question?
- Have the needs of disabled students been adequately catered for?
- Is the language chosen such as not to unduly handicap those for whom English is not their first language?
- Has some inappropriate cultural bias been introduced?
- Has the anonymity of scripts been assured?

Finally, if one’s concern is no more sophisticated than: ‘How can one write an exam question without just using the same one as last year and changing the numbers, which doesn’t cause one too much work in marking and which tests what is wanted?’ The answer lies in an analysis of last year’s question in terms of its learning objectives, followed by a new question which satisfies the same objectives, but for a different content. That should not be too difficult, and is not to be despised.

Some problematic features of traditional Assessment

Reliability and Validity
The most basic features of traditional assessment are:
a. That it must measure reliably, i.e. be consistent over different examiners, but also;
b. That it must be valid, i.e. measure what it is designed to measure.

These two features of assessment are not independent of each other, and in all but the most basic assessments (e.g. testing memory) there must be a trade-off between them. It is often assumed that multiple choice questions are 100% reliable, but this is not so. They obviously are 100% reliable in marking, but they are not in setting, where ostensibly equivalent questions may be of very different difficulty for particular students. In consequence, while the best and the worst may well be equally identified by equivalent tests, the ranking order in the middle may be very different. What must never be done is to sacrifice validity in order to increase reliability, e.g. by expecting students to learn at the higher skill levels, which can be assessed only moderately reliably, and then to test at the lower levels, which can be assessed much more reliably.

‘There must always be a trade-off between validity and reliability with validity being dominant’.

This is because students’ learning is guided by the assessment to come – the objectives being assessed largely become the students’ learning objectives – the so-called backwash effect.

**Connoisseurship**

The unreliability of assessment is generally considered more acceptable in disciplines with a strong creative and/or aesthetic component, and it is there that the concept of ‘connoisseurship’ originally arose. However, if it is accepted that all good assessment is to some degree unreliable, then perhaps it becomes acceptable to use the concept of connoisseurship also qualitatively in forms of assessment in other disciplines (Eisner 1985), e.g. in portfolio assessment (see below). Such assessment is often referred to as ‘impression marking’, but the important point to bear in mind is that the impression must be agreed by the examiners in advance – and these examiners should be expert, not only in their discipline, but also in examining. This is what is meant by connoisseurship. It is however often wise in such situations to confine oneself to pass/fail assessment, since reliability there is usually greater than in more finely graded assessment and – if faulty – affects far fewer candidates.
To Grade or Not to Grade

Increasingly, the grading of degree work along a single dimension is being called into question. Is it really meaningful to describe three or four years’ work in terms of a single number? If not, then it is time that the reporting of degree results was done in a way that more meaningfully reflects what students have done, and produced, during their course. This can be done most readily through a ‘profile’, which replaces the degree certificate. A profile may be no more than a ‘transcript’, in which the individual assessments are allowed to speak for themselves and are not conflated into a single degree class. However, a genuine profile ought to assess other aspects of student learning which are difficult or even impossible to grade, and hence may include some assessments done on the traditional classified basis, some on the basis of pass/fail – perhaps through connoisseurship assessment, some brief verbal reports or reflections and, in some instances, perhaps no more than a certification of attendance. One advantage of such a compilation is that it also offers students the opportunity to include specific items of which they are proud, and to have them acknowledged in the crucial assessment arena. Such variety more appropriately meets the needs of different learning objectives and goes well beyond the American ‘transcript’, in which all judgments are expressed in grades. Universities might still want to provide degree certificates, but these would simply state that, on the basis of the attached profile, a student has been considered worthy of a degree. The recent (2010) trialing of HEAR (The Higher Education Academic Record) in the UK may signal a large-scale move in the direction outlined in this paragraph. [http://www.universitiesuk.ac.uk/Publications/Documents/Burgess_final.pdf]

Process Assessment: The Assessment of Mental Skills and Abilities

Students have always been expected to develop certain higher order mental skills, but it has often been assumed in the past that they would acquire those skills in the process of learning and that these skills could not be explicitly tested. However, as the development of these higher order skills is often the most important outcome of learning at degree level and is certainly something much valued by employers, the explicit assessment of high level skills has become of great importance. The kind of skills that will be considered below go beyond the rather trivial ones, like numeracy, and extend the meaning of ‘skills’ to include mental abilities (often referred to as ‘higher order skills’) such as those associated with problem solving, criticality and creativity, as well as social skills,
such as communication and team work – all against a background of Materials education. Attempts to treat such abilities and skills as generic, and hence transferable, should be avoided; the very concept of transferability is one that lacks an adequate theoretical, as well as evidential, basis.

Coursework Assessment
As has been argued in the last section, skill learning does not lead to outcomes in the way that knowledge learning does, and can generally be assessed best through the assessment of the processes that lead to the development of the skills. In principle, a well-known way to achieve this is through coursework assessment as this is particularly suitable for assessing process objectives. Even if there are product objectives of skills, e.g. a finished artefact or a solved problem, which respectively assess creativity and genuine problem solving abilities, these cannot be assessed under the stresses and time pressures inevitable in formal examinations. In these cases, it is essential to use a method which is not strictly time limited, such as coursework assessment. However, it is then largely meaningless – but is done all the time – to lump such coursework assessment in with a formal examination assessment into some aggregated mark. However, the reporting of process learning through coursework is not straightforward, and much of it is either too simplistic in its reporting – mostly through products such as essays and reports – or unnecessarily unreliable through the lack of a formalised reporting process.

Portfolios
A formalised reporting process, which has existed for a long time in architecture and in art and design courses, is the portfolio. This usually consists of a number of products, e.g. artefacts, and/or accounts of learning processes. The guiding principle is that a portfolio documents students’ work, largely or entirely selected by them, and normally including ‘evidence drawn from practice and, crucially, usually containing reflective commentary’ (Baume and Yorke 2002, p7). Here we are on largely unexplored ground, as far as Materials education is concerned – Baume and Yorke were concerned with teacher education! To what extent there should be such a form of assessment in Materials education – and indeed what form such portfolios might take – remains to be found out. At a Materials Science assessment workshop, used in compiling this Guide, the following were suggested, as linking process evidence with skills:
Teaching Materials Engineering: an updated guide

- Reflective writing (criticality);
- Case study (criticality);
- Artefacts (creativity);
- Computer programs (creativity and communication skills);
- Learning experiences (life skills);
- Project work examples (problem solving and group skills);
- Web pages (communication skills);
- Extracurricular activities (initiatives);
- Publications (communication skills);
- Patents (management skills).

An important feature of portfolios is that they treat students’ achievements positively, i.e. in terms of what students have achieved – all too many examinations are designed to discover what students have failed to achieve. Portfolios are particularly suited to the assessment of high-level skills, such as those contributing to problem solving, criticality and creativity, since students present their learning development over time. Such development is very individual and makes it impossible to treat all students in the same way, which in turn leads to a very different interpretation of what is ‘fair’. Instead of fairness being based on everyone being treated identically, in portfolio assessment, fairness is based on the concept of every student being given an equal opportunity to show their best work. Incidentally, this makes the most common form of plagiarism, copying from each other, almost impossible. Also, as Yorke (1988, p181) argues in a seminal article, ‘where the detail of performance is concerned, the emphasis is switched from prior expectation of outcomes to post hoc recognition that what has been achieved is consistent with the general expectations of the reward’. This appears to shift assessment firmly into the interpretivist mode. Going further, Knight (2002) argues that:

- Summative assessment should be restricted to what can be reliably, affordably and fairly assessed, in the main the assessment of knowledge;
- Other curricular aspects, and in particular skills development, should be formatively assessed, to signal what is valuable;
- In consequence, HEIs may be ill advised to provide summative feedback about many achievements of interest to employers etc;
Instead they ought to help them to make their own judgments about students’ achievements in such areas.

This last point would require some education of employers, to get them to base their judgment of a student’s work (as expressed in a portfolio, in which students have made their own claims through self-assessment) on the basis of the formative feedback which the student had received. These self-assessments would of course have been commented on within the portfolios by teachers, and employers could then judge the evidence from these portfolios in relation to their requirements of a future employee. The essence of the argument is the need for portfolios, based on formative feedback and in the first place often self-assessed, for curricular aspects that relate largely to processes.

**Portfolio Learning and Assessment**

Portfolio learning requires students to be independent learners, with their teachers acting as facilitators rather than as sources of knowledge; a teacher ceases to be in authority, although they remain an authority in their field of knowledge. Two other features are that much of the learning takes place in groups, and that students have to learn how to reflect on their learning. However, the pay-off is that students are then able to demonstrate the kind of skill development which traditional teaching does not foster, and which traditional examining does not assess.

The essence of portfolio assessment is that it is based on the documentation of ongoing learning experiences, as well as outcomes, and it may include self-assessment by the student. It is difficult to see how the assessment of ongoing learning experiences could be achieved in any other way, but it certainly makes reliability harder and, for that reason, this guide will suggest (in the next section) that the assessment should be holistic and purely on a pass/fail basis, i.e. not graded. (The very applicability of the concept of reliability to such assessment has been critiqued by Johnston [2002]). Furthermore, if assessment is to be based on portfolios, then both students and staff have to be made familiar with the concepts and execution underlying this method of reporting learning achievements. This is very obvious, but it still needs saying, since all too often innovations in teaching, learning and assessment fail because students and staff have been inadequately prepared for them. The introduction of portfolios necessitates substantial educational development for both teachers and students. Not only do they constitute a very different
form of reporting on the achieved learning, but they also take a very different approach from the traditional one to the learning process. In general, this will also include the development of skills such as those on which group learning and reflection are dependent – this in addition to the skills that are already a focus for development.

The style of working in relation to portfolios is alien at present for both students and tutors, so it is necessary to encourage some shifts in learning practices such that everyone learns why and how. Advice to be given in connection with portfolios can be summarised as follows:

Advice to tutors:
- To cease didactic teaching and become facilitators of learning;
- To appreciate the difference between being in authority (now wrong) and an authority (still right).

Advice to students:
- To increasingly be responsible for and take control of their learning;
- To use their teachers as one of many sources for their learning;
- To learn to learn co-operatively with fellow students.

Advice to students and tutors, to include information on and help with:
- Portfolio construction – standards, content, length, style etc, including examples;
- How to reflect on one’s learning;
- The nature and practice of self-assessment;
- Formulation of assessment criteria.

Advice to assessors after reading a portfolio, but before its assessment:
- Discussion of expectations;
- Formulation of detailed criteria, in concordance with the declared criteria established by tutors and students.

Advice to assessors after assessment:
- Assessment should be criterion – not norm – referenced;
- Criteria should be general and non-specific;
Assessment should be holistic and qualitative.

An example of the use of portfolio assessment in Engineering is provided by Payne et al (1993). As summarised by Johnston (2002) it includes:

a. **Need for a Professional and Personal Development programme:**
   - Students (1st & 2nd year) to gather, evaluate, review and present relevant material for portfolio;
   - Weekly sessions to discuss progress;
   - Tutors to meet regularly to discuss;
   - Students to be portfolio assessed already in their first year;
   - Assessors need training;
   - Students should be assessed in job or work related context:
     - Application of knowledge and skills;
     - Functioning of potential professional engineer.

b. **Difficulties:**
   - Attendance poor in Year 1, which was not assessed;
   - Staff resistance to training;
   - Time pressures on staff;
   - The need to pilot first with a small group.

c. **Portfolio assessment led to other beneficial developments in the course.**

For an inspiring article on portfolios and their use, see Rust (2000).

**Assessment of Attitudes**

The difficulty with designing attitude assessments is that in traditional forms of assessment, e.g. essays, it is almost impossible to distinguish a genuine from a pretended report. This has been the case for a long time, e.g. Whyte (1956) had a section on ‘How to cheat on personality tests’. However, the development of a student, as documented in a portfolio, together with its self assessment, has the potential of assessing attitudinal development and change.
Standards and Criteria for Assessment
We can now compare positivist and interpretivist approaches to assessment:

<table>
<thead>
<tr>
<th>Positivist</th>
<th>Interpretivist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective reality exists</td>
<td>Reality socially constructed</td>
</tr>
<tr>
<td>Objective standards can be set</td>
<td>Assessment by interpretive community</td>
</tr>
<tr>
<td>Assessment does not involve students</td>
<td>Assessment involves students</td>
</tr>
<tr>
<td>Importance of reliability and validity</td>
<td>Dependability replaces reliability</td>
</tr>
<tr>
<td>Conflict between reliability and validity</td>
<td>Transferability replaces validity</td>
</tr>
<tr>
<td>Check on quality in outcomes</td>
<td>Check on quality within process</td>
</tr>
<tr>
<td>Fairness in uniformity</td>
<td>Fairness in diversity</td>
</tr>
</tbody>
</table>

The concepts of dependability and transferability need further explanation. The former is a measure of the stability of data over the process of assessment (e.g. portfolio assessment can cover a substantial time period); the latter is concerned with the extent to which salient conditions match in supposedly similar assessments. These are not easy concepts and for a more complete description see Guba and Lincoln (1989), pp421-42.

Degree Classification
By now it should be clear that the conflation of grades or percentage marks of different parts of a degree assessment into a single final degree class not only obscures most of the valuable information obtained, but has aspects that are so arbitrary (what weight to be given to different parts of the assessment, how to reconcile different means and different spreads of marks, etc) that the abolition of the final degree class must be seriously considered. Its main purpose is that it is supposed to have predictive value, particularly for prospective employers, but that is patently untrue. Its main value to employers would appear to be that it provides a
first sift to cut down the number of applications for a post to manageable proportions, but this is not a sufficient justification for an essentially meaningless procedure which is expensive in resources and can have lasting psychological consequences on students who fail to get a particular class of degree. The degree certificate should therefore be replaced by a profile that states in some detail the extent to which students have succeeded in the different parts of their courses and how these different parts were assessed. If this is done, then portfolios might well be graded merely as pass/fail, holistically and on the basis of connoisseurship, which would significantly reduce the problem of the reliability of their assessment. Most employers spend very large sums on the recruitment and first appointment of graduates; what has now to be added is a short training booklet or course that will enable them to make the most of the large amount of information provided by a profile or portfolio. The proposal to abolish degree classification may well be the most contentious one in this booklet, although it received a very favourable hearing in what we believe to be the only conference which addressed that subject (Winter 1993) and now has emerged – in the form of HEAR (see above) as part of a government agenda for higher education.

Plagiarism and Collusion
It has already been suggested that much plagiarism can be avoided, if students are treated as individuals, rather than being all treated the same. This may not of course always be possible or indeed desirable. Thus, in a large first year class, all students do the same laboratory experiments and many are likely to copy from each other. This can be kept in check by adding an oral assessment of one or two laboratory reports, which have been chosen by the examiner. Finally, as it is important at times for students to work in groups, it is vital to discuss with them where collaboration ends and copying starts.

Of course plagiarism in the second decade of the 21st century frequently involves the unattributed use of material sourced from the internet. This is a persistent problem, often with strong cultural overtones, which can be addressed at a superficial level by the use of semi-automated plagiarism detection software (e.g. Turnitin). However, a more sophisticated approach is to use assessment methods which require understanding rather than recall or description. Such questions are often called 'concept questions' and are described in more detail below. It is very difficult to find the answer to a good concept question on the internet!
Concepts
I have noticed that the word ‘concept’ and its derivatives has been used more than forty times in this booklet. We clearly think that concepts and conceptual understanding are important. This is therefore probably a good point to elaborate on the use of ‘concept questions’ for both formative and summative assessment.

Concept questions are questions for students which seek to explore their understanding rather than their recall or knowledge. They have been developed by teachers in various fields, but principally in physical sciences, over the twenty years since about 1991. Concept questions could be used for either formative or summative assessment, but one of the huge advantages they offer is the potential for the teacher to discover the misconceptions held by his or her students in time to do something about this deficit. Consequently there are more reports of concept questions being used in class, or in pre-course surveys, than in summative examinations. Krause and his colleagues have devised concept questions in the specific Materials domain (Krause, Kelly, Triplett, Eller, & Baker, 2010).

Mazur uses concept questions in association with personal response systems (clickers), to force the students to think when answering in-class questions. He has published many of the questions in his book on ‘Peer Instruction’. (Mazur, 1997). Additionally I have collected more than 80 such questions from colleagues attending the international CDIO Conference in Copenhagen in 2011. I am happy to send a copy of these to any interested reader [goodhew@liv.ac.uk].
Part 4: How to evaluate your own success

What is Evaluation?

The term evaluation is used in educational literature in different ways. In the original guide, Ivan Moore introduced it as a systematic process. For example, it is common to evaluate the effectiveness of a system or outcomes of a project – usually at the end. This form of evaluation has limited benefits for the formative development of an improved project or system, unless the outcomes of the evaluation are fed back in time to make adjustments to the system. For the purposes of these guidelines, evaluation is taken to mean the collection, by an individual teacher, of feedback information so as to inform their developing practice in supporting the students in attaining the desired learning outcomes.

Why should we evaluate?

As Material Scientists and Engineers, we recognise the role of feedback in any design or control system. As professional teachers, we should recognize the need to continually evaluate our approach to supporting students in their learning, so as to improve it. Even if we believe that we are providing an excellent learning environment for our students, we know that the nature of students is constantly changing, so what may be appropriate today may not be appropriate in a year’s time.

A model of evaluation was provided by Ramsden (1996). We begin our teaching with some form of theory about what constitutes good teaching. Often this is based on our own experience as a learner. Occasionally, it is based, in part, on scholarship or formal study. This theory relates to different contexts such as undergraduate programmes, postgraduate programmes or professional programmes. This, in turn, influences our teaching practice, which is designed to support the students in achieving some explicit outcomes. Where these outcomes are not comprehensively achieved by all students, then feedback allows us to modify our inputs (theory, contexts and practice) in order to achieve closer alignment with the outcomes. Evaluation is the process of identifying the difference between the desired and achieved outcomes and of determining what changes might usefully improve the outcomes.
What outcomes are we trying to evaluate?

There are two main ways of considering outcomes. The first relates to the subject benchmark statements described in the first pages of this booklet and the second to the Engineering Professors Council’s (EPC) ‘Engineering Graduate Output Standard’. The benchmark statements are widely available and vary from one Engineering discipline to another, as described above previously. However, the output standard is rather less well known, but is generic and is outlined below:

Put simply, the EPC sees Engineering graduates as having:

Ability to exercise Key Skills in the completion of engineering-related tasks at a level implied by the benchmark statement.

They then see the engineering process in six stages:

- Ability to transform Existing Systems into Conceptual Models;
- Ability to transform Conceptual Models into Determinable Models;
- Ability to use Determinable Models to obtain system Specifications in terms of parametric values;
- Ability to select optimum Specifications and create Physical Models;
- Ability to apply the results from Physical Models to create Real Target Systems;
- Ability to critically review Real Target Systems and personal performance.

These form the seven ‘Ability to’ (A2) statements. Each one is expanded in the EPC booklet on the Output Standard [http://www.epc.ac.uk/uploads/output_standards/epc_egos_pbwg_200202.pdf]. Although they are couched in language which will be more familiar to a mechanical or manufacturing engineer, the engineering process does map on to the Materials domain. We certainly use conceptual models and specifications; however our ‘target system’ is more likely to be an alloy or a composite material than an aircraft sub-system.

These outputs are often reflected in programme and module specifications and clearly identify the intended outcomes of a
course of study. (Of course, assessing whether students have developed these abilities is far from simple.) All of these kinds of statements attempt to identify the knowledge, understanding and skills that students will have on graduation. An alternative (or additional) way of considering outcomes is in terms of the students’ learning skills. That is, their developing capacity to engage in deep learning and to learn independently. This includes taking responsibility for their own learning, developing information and study skills, and maintaining motivation to learn.

An independent learner might be categorized as someone who 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.

In addition, it could be argued that:

- They have well-founded conceptions of learning;
- They have a range of learning approaches and skills;
- They can organize their learning;
- They have good information processing skills;
- They are well motivated to learn.

What should be the principles of evaluation?

1. Evaluation should be an integral part of our teaching practice;
2. Evaluation should be an ongoing process, so that we learn from systematic reflection;
3. Evaluation should be participatory;
4. Evaluation should enable us to make appropriate modifications along the way;
5. Evaluation should enable us to make judgements on specific teaching sessions, but also to draw out wider implications.

What are the standard techniques for evaluation?

In the UK there is a National Student Survey (the NSS). However it is only completed at the end of a whole degree programme and asks only very general questions. It is therefore totally inadequate
for the purpose of giving an individual lecturer evaluating feedback on their teaching. (Indeed we believe that it is also inadequate for any other purpose, but that is an argument for another time and place.) Most institutions have their own evaluation questionnaires. These have often been designed to satisfy external quality agencies and to audit quality but not necessarily to help to enhance it. Ramsden has developed a Course Experience Questionnaire, based on research into student learning, which focuses on identifying those approaches which foster deep learning in students. The appendix on page 113 shows a 25-question version of this questionnaire which comprises 5 sub-scales:

- Good teaching;
- Clear goals and standards;
- Appropriate assessment;
- Appropriate workload;
- Generic skills.

This questionnaire attempts to identify the attitudes and intentions of teachers in a way that allows them to improve the way they encourage deep learning approaches in the students.

**What do the scales mean?**

**The Good Teaching Scale: Questions 3, 7, 15, 17, 18 & 20**
The scale is characterised by teaching practices which include the following: providing useful and timely feedback, clear explanations, motivating students, making the course interesting, and understanding students’ problems. Lower scores on this scale are associated with the perception by students that such practices occur less frequently.

**The Clear Goals and Standards Scale: Questions 1, 6, 13 & 24**
Practices characteristic of this scale relate to the establishing of clear aims and objectives for a course and clear expectations of the standard of work expected from students. It is possible to employ the good teaching practices described under the Good Teaching Scale, without implementing practices characteristic of the Clear Goals and Standards Scale.

**The Appropriate Assessment Scale: Questions 8, 12, 16 & 19**
This scale deals with the extent to which assessment measures higher-order thinking and understanding rather than simple factual
recall. This scale does not probe other important aspects of assessment practices such as the congruence of the assessment with the material actually taught, the level of difficulty and the consistency of the quality of the assessment.

**The Appropriate Workload Scale: Questions 4, 14, 21 & 23**
Higher scores on this scale indicate a perception of reasonable workloads. Heavy workloads do not necessarily equate to high standards and expectations so the wording of the items probes the extent to which heavy workloads interfere with student learning. Heavy workloads tend to preclude students from engaging with and understanding the material they are learning. Instead, many students adopt surface approaches to learning as a strategy for dealing with high workloads.

**The Generic Skills Scale: Questions 2, 5, 9, 10, 11 & 22**
This scale reflects the extent to which students perceive their studies to have fostered the development of the generic skills recognised by the university as being a valuable outcome of university education, in addition to discipline-specific skills and knowledge.

*Note:* these generic skills may be determined to be key skills, employability or any such skills as may be deemed to be important in your course, department or university.

**When should we evaluate?**

The Ramsden questionnaire meets the last principle of evaluation above. That is ‘evaluation should enable us to make judgments on specific teaching sessions, but also to draw out wider implications’. However, a common difficulty with this form of evaluation questionnaire is that it is often only processed at the end of a period of study, and any modifications to teaching practice will not benefit the students who completed the forms (see the earlier comments on the NSS). It is often very effective (and easy) to conduct short, regular evaluation activities. Below are three possible sets of questions that could be used at the end of ANY teaching session. They all help to provide immediate feedback, both to the student and to the teacher in a manner that allows immediate action to be taken to improve the learning.
Please answer each question in 1 or 2 sentences:

1. What was the most useful or meaningful thing you learned during this session?
2. What question(s) remain uppermost in your mind as we end this session?
3. What was the ‘muddiest’ point in this session? (in other words, what was least clear to you?)

1. What would you like me to stop doing?
2. What would you like me to start doing?
3. What do you want me to continue to do?

1. What are 1 or 2 specific things we do that help you learn in this course?
2. What are 1 or 2 specific things we do that hinder or interfere with your learning?
3. Please give me 1 or 2 specific, practical suggestions on ways to help you improve your learning in this course.

The first set of questions relates to teaching (or learning) sessions, such as a lecture or practical class, so it might be used at the end of virtually every session. The third set makes reference to learning throughout a course, so it might be used at the midpoint of a course of teaching. The second set might be used on, say, a monthly basis. Of course, useful feedback can be gained from processing these questions at any stage in a course of teaching.

How might we use these questions?

Perhaps the most immediate way to use these sets of questions is in a ‘one-minute questionnaire’. You could display the questions on a screen and invite students to produce short responses on paper and drop them into a box as they leave the room – or you could use personal response systems if you have already been using them in this class. However, the students might provide more thoughtful and meaningful evaluations if they are given a few minutes to consider the questions. You could try paired discussions around the questions, for example, with written or poster feedback, or invite them to submit a short piece of reflective writing. These techniques take a little longer, but often provide more considered responses.
Designing your own evaluation

The model presented in the introduction to this section discussed different contexts, such as the lecture, the lab etc. It is possible to take such a context, and devise four or five questions designed to evaluate in what ways that form of learning activity was helping or hindering the students to achieve the desired learning outcomes. For example, in laboratory teaching, we might construct five simple statements, which the students would score from 1 to 4 (1= do not agree, 4= strongly agree). A four-point scale avoids the temptation for students to opt for a neutral response. If you prefer to allow them that option, then make it a five-point scale.

- The laboratory brought the lecture material to life;
- The laboratory allowed me to see key concepts working in practice and so understand how theories are applied in real solutions;
- The laboratory stimulated my interest in the subject;
- The laboratory helped my ability to work as a member of a team;
- The laboratory gave me confidence in researching an open-ended engineering problem.

This approach can be applied to any/all contexts, such as lectures, problems classes or group projects. A typical design is shown below.

1. The laboratory brought the lecture material to life;
2. The laboratory allowed me to see key concepts working in practice and so understand how theories are applied in real solutions;
3. The laboratory stimulated my interest in the subject;
4. The laboratory helped me to work as a member of a team;
5. The laboratory gave me confidence in researching and open-ended engineering problem;
6. In the mini group project we worked well as a team, with all members contributing effectively;
7. The mini group project helped me to use presentation skills effectively;
8. Investigative skills were used and new skills learned;
9. I learnt more in this context about the subject matter than we would if we had been in a lecture;
10. The problem class has helped prepare me for assessment in ‘Concept X’;
11. I felt uncomfortable about contributing to the problem class;
12. The problem class helped me make connections between different concepts and relate them to each other;
13. I could explain the concepts of this lecture to another student;
14. I found it difficult to concentrate throughout the lecture.

These evaluation statements were actually designed by participants in a workshop on evaluation. They clearly identify the kinds of learning activities or contexts (in this case laboratories, group projects, problems class and lectures) and the aims of the teaching staff in designing these activities. The next stage is to randomise the questions, and to reword some of them in a negative sense – as in question 12. This avoids the tendency for a student to simply go down the score list and award the same mark to each questions, based on an overall view of the course.

Likert scales (e.g. selecting one response from 4 or 5) are useful, but limited, in providing evaluative information. It would be a simple and effective development to invite the students to provide examples to support their evaluations or to give reasons why they made each response, either for each statement, each section or the questionnaire as a whole.

**In conclusion**

As Materials Scientists and Engineers, we recognise the importance of feedback in maintaining a stable situation or achieving a goal. If the goal is to improve our practice as teachers, then evaluation is an important component of our professional practice as teachers. There are standard questionnaires that can be used and it is relatively easy to design your own questionnaires. However, more reflective, meaningful feedback can be derived from group discussion. Each group can consider all the questions, or you can give each group only one question to consider. Short questionnaires, of three or so questions can be processed frequently and quickly. These will give very useful information to teaching staff which will allow them consistently to adapt and improve their teaching practice. Such improvements can only be to the benefit of the students and of their learning.
Appendix

The Course Experience Questionnaire

1. It was always easy to know the standard of work expected.
2. The course developed my problem-solving skills.
3. The teaching staff of this course motivated me to do my best work.
4. *The workload was too heavy.
5. The course sharpened my analytic skills.
6. I usually had a clear idea of where I was going and what was expected of me in this course.
7. The staff put a lot of time into commenting on my work.
8. *To do well in this course all you really needed was a good memory.
9. The course helped me develop my ability to work as a team member.
10. As a result of my course, we feel confident about tackling unfamiliar problems.
11. The course improved my skills in written communication.
12. *The staff seemed more interested in testing what we had memorized than what we had understood.
13. *It was often hard to discover what was expected of me in this course.
14. I was generally given enough time to understand the things we had to learn.
15. The staff made a real effort to understand difficulties I might be having with my work.
16. The assessment methods employed in this course required an in-depth understanding of the course content.
17. The teaching staff normally give me helpful feedback on how I was doing.
18. My lecturers were extremely good at explaining things.
19. *Too many staff asked me questions just about facts.
20. The teaching staff worked hard to make their subjects interesting.
21. *There was a lot of pressure on me to do well in this course.
22. My course helped me to develop the ability to plan my own work.
23. *The sheer volume of work to be got through in this course meant it couldn’t all be thoroughly comprehended.
24. The staff made it clear right from the start what they expected from students.
25. Overall, I was satisfied with the quality of this course.

*Negatively scored*
Part 5: Example Case Studies

These case studies, C1 to C11, serve various purposes, but represent one of the most valuable resources in the booklet. Most of them are referred to in Parts 1 or 2 of this guide, but they can be read as stand-alone activities in their own right.

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C1: A Review Case Study Assignment

This requires students to gather technical information with regard to materials for a specific product and gain in-depth knowledge about a particular set of materials or products, going much further than could be accomplished in a classroom situation.

Learning Outcomes
At the end of the assignment the students will:

- Have gained in-depth knowledge of specific materials;
- Be able to recognise the basic principles of selecting materials for a particular application;
- Be able to explain materials characteristics and properties, and relate them to performance, manufacturing process, and/or the environment;
- Have developed team working skills, information gathering and communication skills.

Assignment Brief
This assignment combines both individual and group work. Students arrange themselves into small groups. The first task is to select a project from the list. Students must then allocate individual and group tasks for information gathering within the group. Students may submit individual reports and the group could do a presentation that integrates the individual’s contributions.

Suggested Project Titles:
- Dental materials;
- The role of materials in the automotive industry;
- Materials for bicycle frames;
- Materials used in the aerospace industry;
- Body armour materials;
- Materials in the electronics industries;
Teaching Materials Engineering: an updated guide

- Materials in information technology;
- Designing with composites;
- Materials used in sports.

*******

C2: A Reverse Engineering Case Study

This case study involves students taking apart a familiar product and determining the materials used for each separate component. An example could be a Belt Electric Sander. Students can undertake various tests to determine the materials that it is made from. In their reports the students can critically appraise the choice of materials selected and suggest alternatives. The students could analyse the design and possible methods of manufacture of each component. This activity illustrates to the student the integrative role that materials plays in engineering design and manufacture.

Learning Outcomes
At the end of the assignment the students will:

- Be able to recognise the basic properties of materials for a particular component and reasons for selection of that material;
- Be able to recognise the basic principles of selecting manufacturing processes for a particular component;
- Be able to explain materials characteristics and properties, and relate them to performance, manufacturing process, and the environment;
- Have devolved information gathering skills;
- Have improved their written communication skills.

Assignment Brief
The ‘belt sander’ consists of a number of materials and components produced by a range of manufacturing processes.

Investigate and identify the materials used in the belt sander. Explain how you determined what (you think) the materials are.

- Why have these particular materials been chosen? Discuss what alternatives could be employed – why? What properties do they possess/need?
How have the component parts been manufactured? Why has the process been used? What alternative processes could be used?

What are the effects of the process used and the materials on the environment? Is the product recyclable?

Some other ideas on how to engage engineering students are listed below:

- Use web-based material that is easily accessible by the student;
- Try visual animations to help explain the processes/theories involved;
- Present content material in an interactive format;
- Problem-Based Learning makes theoretical aspects more pragmatic for students;
- Use of anecdotes and stories;
- Industrial visits, work placements and visits from industrial experts;
- Exploring everyday uses of materials;
- Utilising memorable models;
- Use ‘Snappy Technology’ – ‘nano’ technology and ‘smart’ materials;
- Links to research topics in the department;
- Use interesting artefacts;
- Industrial component failure is a way of linking relevance of materials to engineering and can help in stimulating student motivation.

******

The following two case studies illustrate how several aspects of environmental issues of materials use can be covered within a single context. Case studies such as these provide excellent methods of combining advanced technical knowledge and commercial/legal/social issues in an interesting manner.
C3: Environmental Materials Used in the Automotive Industry

- End-of-life Vehicle (ELV) regulations;
- Restriction of hazardous materials regulations;
- Requirements for greater fuel efficiency.

The main challenges facing the automotive industry at present include:

- End-of-life (ELV) regulations;
- Restriction of hazardous materials regulations;
- Requirements for greater fuel efficiency;
- Emission reductions;
- Improved safety;
Aesthetic design;
Cost competitiveness.

Several of these are beginning to have a significant impact on the materials selection and design issues within the automotive industry. For instance, the ELV regulations will specify recovery and recycling rates at the end of a vehicle’s lifetime, the responsibility for which will rest with the producer. They will also require the use of a minimum amount of recycled material to be used in new vehicles. The hazardous materials regulations will impose further restrictions on materials use and how they can be treated at the end of their life. The requirements for improved fuel efficiency tend to drive materials usage towards reductions in vehicle weight.

The two most significant requirements for materials selection and design are becoming the need for low weight and the requirement for recyclability. Light weighting tends to favour greater use of polymers and polymer composites, although designers with steel have responded to this via initiatives such as the Ultra Light Steel Auto Body (ULSAB) project. Weight reductions can also be achieved by the greater use of multi-material components and adhesive bonding.

Recyclability tends to favour the more traditional metallic materials (steel and aluminium), with fewer different materials used in a vehicle, in larger single components that are joined by more mechanical means. The two requirements (both with environmental protection justifications) tend to drive materials selection and design in different directions. The relative importance of these requirements, and hence the most environmentally-friendly design route, provides a very good subjective discussion point for students.

An interesting new use of materials in this sector is found with natural composites (with plant fibres such as hemp and flax replacing glass and carbon). With suitable degradable polymer matrices, these materials can provide low weight together with recyclability via composting.

*******
This case study relates to waste legislation, the WEEE directive, which specifies minimum collection and recycling rates for waste electrical and electronic equipment. In this case, the most interesting materials issues arise when this legislation is taken in conjunction with that dealing with hazardous waste, e.g. the ROHS directive. Many components within WEEE contain materials that are designated as hazardous and require special treatment. Examples include:

- Lead solders;
- Phosphorus coated monitor and TV screens;
- Mercury switches;
- Batteries;
- Brominated flame retardants in plastics;
- Refrigerants.

Consideration of these allows in-depth study of the materials issues (for instance what is the physical mechanism that requires a phosphorus coating on a TV screen), to consider alternatives that can be used in future (e.g. what other low melting point metal alloys could be used as solders) and also what problems they are likely to pose in waste treatment. One of the most important examples of the latter issue is that of flame retardant identification with plastics.

An estimated 30% of waste plastics from IT contain brominated flame retardants, which are designated as hazardous. The WEEE directive requires minimum levels of recycling of plastics from IT. Unless the brominated flame retardants can be accurately identified and separated, it will be impossible to recycle any. At present, identification methods are yet to be proved as 100% effective, and so there is a potentially huge technical problem awaiting us. Detailed consideration of this issue is an excellent way for students to learn about polymer additive technology and chemical identification methods.
Useful Information Sources

Landfill Regulations

WEEE directive

ROHS directive

Environmental Protection Act 1990

COSHH Regulations
http://www.coshh-essentials.org.uk

Guide to Climate Change Levy
http://customs.hmrc.gov.uk/

Guide to Landfill Tax
http://www.hmrc.gov.uk/index.htm

Recoup (Recycling of Used Plastics Ltd)
http://www.recoup.org

WRAP (Waste & Resources Action Programme)
http://www.wrap.org.uk

**********
C5: Chocolate – A Materials Approach

Length: 3 hours (one lab session)
Level: 1st year Materials and Engineering course
Aim: To demonstrate the relevance of, and application of, scientific theories developed in lectures to a single material. To encourage students to use knowledge from a number of lecture courses in another setting

Key skills: Group work, presentational skills, time management
Assessment: Question sheet and group presentation

Students are assigned to groups of 4–6 for the session. Each group is presented with a pack of information about chocolate (raw materials, manufacture, properties, marketing data, heat treatments, compositions, structures etc) and a set of questions to answer. There is too much information for everyone to read everything, hence the students need to set priorities and allocate tasks to ensure that all the research is completed in time. The groups are also required to give a 5 minutes presentation to the class (they are provided with OHP’s and pens) on a given topic, different for each group (e.g. control of taste through composition, structure and processing). The students therefore have to share their findings from the reading and relate the information to their knowledge from other lectures (e.g. what is shell casting, tempering etc.). A final component to the case study is taste testing of a range of different chocolate samples to illustrate the role of composition (sugar, milk, cocoa levels), particle size etc. This element is designed to be both fun and informative, the students particularly like to try the American chocolate, which is almost universally disliked, and determine what the differences are that change the taste compared to the different English chocolate types.

**********
C6: Space Shuttle Challenger Disaster

Length: 2 weeks (2 x 2 hour lecture sessions)
Level: 1st year Materials and Engineering course
Aim: To illustrate the importance of Materials Science in a real life situation and to encourage students to consider the role of an engineer in the workplace
Key Skills: Individual study, written communication, research skills
Assessment: Individual report in the style of a popular science magazine article

This case study examines the issues surrounding the space shuttle Challenger disaster and requires students to consider the problem from three main viewpoints: technical, economic/political and social. There are two scheduled sessions, the first is used to outline how and why the disaster occurred. Clips from a NASA video are used to present technical information on the topic, and video clips of an interview with an engineer involved in the disaster are used to give further insights into the event. Students are encouraged to address issues as they arise and participate in class discussion. At the end of the session the students are told to research independently into the topic to gain a greater understanding of the case study. The following session includes three mini-lectures by technical experts that cover the political history of the programme, the impact on society of the teacher in the space programme and the technical cause of the disaster (rubber O’ring performance and rocket booster design). These are approximately ten minutes long and after each presentation students are expected to interview the experts to find out further information. Students will have been made aware of this in the previous session so have the opportunity to prepare questions. The session finishes with a role play exercise which requires three volunteer students to act out a telephone conversation that took place between the NASA government and the technical engineers from the company Morton Thiokol.

Students are asked to write an article in the style of a popular science magazine (for example New Scientist/Materials World) considering one aspect of the overall problem. Example articles from Materials World are provided as guidelines for the required technical level and format of the report.
C7: Metallic Bicycle Components

**Length:** 5 weeks (1 introductory lecture, 3 practical sessions, 2 group sessions and a presentation session)

**Level:** 2nd year Sports and Materials Science course

**Aim:** To illustrate why given materials are used for a particular application. To give students the opportunity to produce and analyse experimental data in conjunction with carrying out independent research on the topic. To help them to understand and interpret microstructures in relation to material properties

**Key skills:** Group work, presentation skills, time management

**Assessment:** Group report and presentation and an individual executive summary

Students are assigned to groups of 5–6 and investigate a number of components: frames, spokes and rims. It begins with an introductory lecture where students are briefed on the topic and the case study objectives are set. The structure of the case study work is also explained to the students in terms of how the practical and group sessions operate. When designing the case study it was clear that it was not practical for all the students to attend all the experimental sessions. To tackle this problem, students are told that each experimental session is limited to two members from each group and different pairs are required for each session. This ensures that all students attend at least one practical session. Each group then has access to a complete set of experimental data, but this depends on good group management and communication. Two formal group sessions are scheduled in the two weeks that follow the practical week. Each group meets with the lecturer and post-graduate assistants for ten minutes to give a five-minute presentation and provide a one-page summary of activity and future plans. If a group member does not attend, they lose marks. The aims of the group sessions are as follows:

- To ensure that progress is being made;
- To enable appointments to be made with the post-graduate students to answer specific technical questions;
To provide an opportunity for the group to meet and detail activities for the following week;
To ensure the egalitarian operation of groups.

Students are expected to carry out independent research on the topic to use in conjunction with their experimental data. In the final weeks, students address their case study objectives by handing in their group report and giving a presentation. They also have to submit an individual executive summary, which is used as an individual component to the group work.

*********

C8: Windsurfing Masts

Length: 3 weeks (Introductory lecture and presentation session)
Level: 1st year Sports and Materials Science course
Aims: To demonstrate the application of theoretical concepts in an item of sporting equipment and to encourage students to carry out independent research and study on the topic
Key skills: Group work, presentation skills independent research
Assessment: Group Report and presentation and peer assessment

This case study requires students to work together in groups of 5–6 to investigate materials selection and construction for windsurfing masts. This is the first case study out of four in which first year students participate. To help the students understand this new type of learning, part of the introductory lecture is used to brief them on what is expected of them when taking part in case studies. Following this, background information on mast technology provides some details in the areas that students need to consider. Groups then assemble and are given ten minutes to brainstorm what properties the masts may require and suggest suitable materials. Students then discuss and share their ideas. Finally, students are given a basic materials selection chart and are asked to consider materials selection on two variables, density and stiffness. This teaches students how to use these charts and also highlights the type of materials they should be considering.
Windsurfing masts have to fulfil a certain criterion and students are asked to research into the types of material that could be used to meet that criterion. They are also asked to discuss production methods for the mast based on a chosen construction material. This case study asks the students to consider two possible designs and to suggest materials and production processes.

**Design 1 (to be considered for a weekend sailor)**
- Force 3 wind
- Required modulus - > 10 GPa
- Required strength - > 100MPa

**Design 2 (applies to competition masts)**
- Force 5 wind and above
- Required modulus - > 100 GPa
- Required strength - > 1 GPa

For the rest of the case study students work independently in their groups to research into the topic. They are expected to organise their own work and delegate tasks within the group. In the third week they reassemble to give their presentations, submit their group report and carry out peer assessment.

**********

**C9: Joining Processes**

**Length:** 7 weeks (Introductory lecture, interim presentations, final presentations)

**Level:** Year 2 Materials Science and Engineering course

**Aims:** To demonstrate to students the application of processes for joining materials which has been covered in year 1 lectures, but also to extend to consider design, defects, production methods etc

**Key skills:** Group work, poster presentation skills, time management

**Assessment:** Group Report, poster presentation and peer assessment

Students work together in groups of 6 to specify joining processes for specific components. This activity contributes to a third of a
module that was previously taught by lectures. Basic processes for joining are covered in year 1 and this case study extends the analysis to include design, defects and production of joints with reference to specific requirements. The case study involves a number of activities that overlap with the other modules the students are taking, such as Selection and Design, Fatigue and Fracture and Materials Processing. It begins with an introductory lecture in which the lecturer outlines the case study format and gives some background to the topic. Students are then put into their groups and given case study specifications. Each group is assigned a different component for which they have to specify joining processes. These are:

- Pipeline for carrying oil in a coastal environment;
- Power station heat exchanger bundles;
- Lightweight tube structure (linked at both ends) e.g. for a bicycle frame;
- External tram body;
- Box girders for bridge section.

Students must arrange a meeting with the lecturer after the first week of the case study, after which the groups should contact the lecturer as needed during the rest of the case study. In the fourth week, students are required to give a ten minute interim presentation on their work to date. This provides an opportunity for the lecturer to gauge the groups’ progress. The assessment for the activity is made up of three components; a final group report, a poster presentation and the completion of a peer assessment form. In the final week students submit their report and display and answer questions on their posters.

For more information and further examples please visit the Birmingham web-site at [www.cases.bham.ac.uk](http://www.cases.bham.ac.uk)

**********
C10: Example PBL Case Study: ‘The Court Case’

The Crown vs Professor Ton Peijs:
Professor Ton Peijs was charged that on the first day of May 2001 he did wilfully, while taking part in an anti-capitalist demonstration in the city of London, damage a restaurant belonging to the CJD-burger chain in Oxford Street. The prosecution provided forensic evidence linking Professor Peijs to the scene of the crime. The defence team, concerned by the overwhelming force of evidence held by the prosecution, decided to hire several independent consultants (the PBL groups) to advise them and to give evidence in court. Several different pieces of evidence were provided against Professor Peijs; one for each group to examine.

For example, team E were given a sample Exhibit E2 of fibre from the wall of the CJD-burger restaurant which they alleged to have come from Professor Peijs’ pullover. A sample of the same black fibre Exhibit E1 taken from his pullover when he was arrested was also provided for comparison.

Exhibit E1: Fibre sample from suspect’s clothing

Exhibit E2: Fibre sample collected from a splinter on the broken door-post of the CJD burger restaurant
The Court met with Lord Justice Reece presiding. Prosecuting counsel was Julian Evans, and defence was conducted by James Busfield. After a brief review of the evidence from the prosecution the defence counsel called upon expert witnesses from each team and invited them to present their evidence. Each PBL group was cross-examined on their evidence by counsel for the prosecution. Exhibit E1 was identified as being a man made polymeric fibre and Exhibit E2 was identified as being natural fibre. As none of the evidence presented by the prosecution was conclusive then the case against Dr Peijs was dismissed.

**********
C11: Sustainable Development Individual Case Study
(as completed by a student, instructions given to student in italics for each section of the case study, showing submission dates for each section)

Name: A student
Product or Process Selected (submit by 29 Oct)
Carbon Fibre Bicycle Frame

Brief Description of scope of product or system, its market situation and your sustainable development concerns: (submit by 29 Oct)

The materials used in a bicycle frame have changed greatly over the years. The most common material used for high end frames is carbon fibre. Introducing this stiff, light and strong material into frame building has changed the world of cycling. Being relatively cheaper than titanium, and lighter and stiffer than aluminium it is the choice of material for most high end frame manufacturers worldwide. However, it can be very difficult to dispose of the frame at the end of its life.

Summary of complete case study (submit by 6 Dec)
In the early 1990s, carbon fibre frames completely took the bicycle market by storm, and have ever since been improving in lightness, stiffness and strength in order to produce the most desired frame at an affordable price. As time has progressed the standard steel – and lighter than steel – aluminium frames have gradually been replaced by carbon fibre. However, although steel and aluminium are reusable materials (either by recycling or mending), carbon fibre frames are simply disposed of at the end of their life. This is due to an inability to recycle carbon fibre.

This has brought many parties to criticise the mass use of carbon fibre. A number of ideas include introducing a more environmentally-friendly material, with the same performing standards, or to look into different ways of recycling.

Here we will look into some sustainable solutions, including a unique carbon recycling plant in Birmingham, and the use of titanium or bamboo instead of carbon fibre.

Background technology for your product or system relevant to sustainable development issues, particularly materials aspects: (submit by 29 Oct)
Constraints
Desired properties:
  Strong;
  High stiffness-to-weight ratio;
  Non toxic;
  Durable;
  Easy to manufacture;
  Aesthetically pleasing.

Common Objectives
Must be a minimal:
  Cost;
  Mass;
  Loss of Kinetic Energy (energy consumption) during use.

The advantage of using carbon fibre to produce bike frames isn’t only that it’s lightweight and stiff, but also that the carbon fibre can be so called ‘fine-tuned’ to enable certain parts of the frame to be stronger than others allowing other parts to be more flexible. For example Cervelo’s R3 carbon frameset has super thin seat stays which reduce weight and increase vertical compliance leading to a more comfortable frame.

Carbon fibre is produced by an almost ‘knitting’ together of several thousand carbon fibres, to produce a yarn. Its low density makes it a suitable material to use in the production of bicycle frames.

A monocoque carbon frame is a frame which has been made from one piece of carbon. This in turn produces an extremely lightweight frame, which is strong in the sense of withstanding the lateral forces placed on a frame when pushing a hard gear on the bike up a hill, but not in terms of its impact toughness. A slow impact crash might end up bending or snapping a carbon fibre frame.

Another problem that seems to be reported quite frequently is a carbon frame losing its ‘liveliness’ (frame feels damp and dull to ride). This turns out to be due to the fatigue over a number of years of use. This creates a problem never really seen before in steel frames, which means the life of a carbon frame is much shorter and so therefore more expensive not only initially but in the long term as well.
Carbon fibre has also been seen as a waste of natural resources when compared to the largely abundant material, steel (from iron). However, carbon fibre is actually a way of using up waste products from the fractional distillation process. David Ward, the product manager for 'Giant' says: ‘Carbon Fibre is made from the “Heavy Bottoms” element of oil... It's a by-product that wouldn't be used for anything else, and in the past would just be disposed of.’ ('How Green Is Your Ride?', Matt Barbour, Cycling Plus, Issue 242, p96)

Framing for product or system in a sustainable development context (submit by 29 Oct)

**Current attitude of Consumers/Users**
To purchase a light, strong frame which will remain durable through usage and last a good while. This, however, does not come cheap. There is, also, very rarely any warranty given for a carbon fibre frame and if it breaks it cannot be rewelded like a steel frame, but must be replaced. Some titanium frame manufacturers offer the consumer a lifetime warranty on their frames. On the plus side, carbon fibre frames are 100% free from any form of corrosion.

**Current attitude of Retailers**
Carbon frames and bikes are relatively expensive to buy from the manufacturer, but as they are also sold for a good price, retailers don't miss out on any profits. With cycle racing on the up, more and more carbon fibre bikes are being bought.

**Current attitude of Manufacturers**
A higher grade of carbon produces a finer product. However, a higher grade of carbon means more cost and so therefore more cost for the consumer. A compromise between cost and quality is made. Manufacturers aren't too concerned about the difficulty of the disposal of carbon fibre, though they could be made to be more aware by the government.

**Current attitude of Pressure Groups**
Environmentally friendly parties are concerned with the increasing amount of carbon fibre being produced. We are unable to recycle, reuse or remanufacture/refurbish carbon fibre. Not only this, but combusting carbon fibre for disposal releases vast amounts of CO$_2$ so carbon is disposed of in landfills.
Current attitude of Government/Regulators
There are no major restrictions on carbon fibre frames from the
government. In fact, cycling is massively being encouraged
throughout the country, promoting good health and a reduction in
carbon emissions from cars. However, disposal of carbon fibre
raises problems. At present there is no way to recycle carbon fibre
materials. More than 100 tonnes of highly valuable material, either
end-of-life goods or scrap from manufacture, goes into landfill
every year in the UK alone. (http://www.bis.gov.uk)

Process flow diag of product life cycle or system (submit by 29 Oct)
Current attitude of any other relevant parties
A bamboo frame company, ‘Bike Bamboo’ say ‘Carbon fibre requires a lot of energy to be produced in its controlled oxidation, carbonisation and graphitisation. The graphitisation process in particular is highly energy intensive, requiring temperatures of ~2600°C for high strength fibres or ~3000°C for high modulus (elastic) fibres.’ This shows that there are companies out there who are environmentally aware, and willing to try and produce change.

Figure 1: Flow chart showing the production of a carbon fibre composite from its raw materials

(John Pilling: http://www.mse.mtu.edu/~drjohn/my4150/class14/class14.htm)
Figure 2: stiffness to weight ratio of some common bicycle materials. Note the massive superiority of carbon fibre. (Materials Sector, 1992)

<table>
<thead>
<tr>
<th>SD Factor →</th>
<th>Depletion of Reserves</th>
<th>Expense</th>
<th>Energy Use</th>
<th>Wastes</th>
<th>Hazard to Consumer Health?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Cycle Stage ↓</td>
<td>Only uses up what would have been disposed of in the past (Matt Barbour, Cycling Plus 2010)</td>
<td>Due to very high temperatures being used, and also an inert gas atmosphere, costs are rather high.</td>
<td>Hugely energy intensive process due to the need for a very high temperature in manufacturing process.</td>
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</table>
### Frame manufacturing using Carbon Fibre

| Carbon Fibre is a finite resource. | Costs of skilled workers for manufacture of hand-built frames. Equipment. | Less energy used than in the production of carbon fibres. | Varies from manufacturer to manufacturer. |

### Distribution to shop/online retailers

| Use of finite resources (fossil fuels) in vehicles for transportation. | Usually shipped from Taiwan by Freight, which is a relatively cost effective method of transportation. | Usually shipped from Taiwan by Freight. Estimated that one frame from Taiwan to the UK uses about 10 litres of fuel or 100km of car travel. (Matt Barbour, Cycling Plus 2010) |  |

### Use

| Expensive to the consumer in regards of its low life, but not its performance! |  |  |  |

### End of Life (Disposal)

| Carbon Fibre is a finite resource. |  | Major problem is the inability to recycle, refurbish and reuse, or |  |

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even mend a carbon fibre bicycle frame. Frame is simply chucked away at the end of its lifetime.

**Scoring matrix (submit by 15 Nov)**

<table>
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<tr>
<th>SD Factor →</th>
<th>Depletion of Reserves</th>
<th>Expense</th>
<th>Energy Use</th>
<th>Wastes</th>
<th>Hazard to Consumer Health ?</th>
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<td>Life Cycle Stage ↓</td>
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<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Distribution to shop/online retailers</td>
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<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>Use</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>-3</td>
</tr>
</tbody>
</table>
End of Life (Disposal) | 1 | 0 | 0 | 4 | 0

Design opportunities matrix (submit by 15 Nov)

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<th>Medium</th>
<th>High</th>
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<tr>
<td>Chance of success</td>
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<td>Low</td>
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<td>Medium</td>
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<td>B</td>
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<tr>
<td>High</td>
<td>A</td>
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Design opportunity A
TITANIUM FRAMES. Titanium is as strong, stiff and just as light as carbon fibre and performs just as well too. Its major benefits over carbon frames are its ability to be remanufactured and fixed if broken, or RECYCLED easily. It is also much less prone to fatigue failure, and will last a lot longer than any carbon fibre frame would. However, the initial production of titanium means high cost and high energy usage, and would have to completely replace carbon fibre for there to be any effect.

Design opportunity B
PROPER INVESTMENTS INTO RECYCLING OF CARBON FIBRE. There's a company in Birmingham called 'Recycle Carbon Fibre Ltd' who brought about, in their own words: ‘[The] world’s first commercial scale continuous recycled carbon operation.’ Although they target the waste from large scale operations such as aerospace manufacturing, they demonstrate that recycling of carbon fibre can be done, so it can and should be done globally with all types of products including carbon fibre bike frames.

Design opportunity C
BAMBOO FRAMES. Bamboo frames are a good alternatively. They are equally as light as steel frames and about 60% of the product is made from sustainable materials. (Matt Barbour, 2010) There are barely any environmental costs of producing a frame from bamboo. However, they are extremely expensive for the consumer. A frame can be priced anywhere from £2000 upwards,
which is the same price you may pay for a much higher performing carbon frame.

*Implementation approach for one of your three design opportunities, which must involve materials initiatives (submit by 6 Dec)*

**Title: Bamboo Frame**

**Impact on scoring matrix: Medium**

**General implementation approach**
The public firstly need to be convinced about the brilliance of bamboo not only for environmentally-friendly reasons, but also for the brilliance of the material in relation to performing bicycle frames. It even has the stats to boast: Bamboo has extremely strong wood fibres that can resist up to 5kN/cm². Steel can resist at most 37kN/cm² whereas the outer fibres of slim bamboo tubes have tensile strengths of up to 40kN/cm². [www.bikebambooo.com/bamboo_properties].

**Technology issues**
A few issues will arise though, due to the technology of bamboo frame productions. Manufacturing of a bamboo frame is, however, a fairly long and complicated process, and even after completion a top of the range bamboo bike will weigh the same as a steel bike, although its production has much smaller environmental costs. 'Bike Bamboo' claim bamboo offers a much more comfortable ride than carbon fibre, but due to its fairly high weight (in comparison to carbon fibre) there may need to be quite a large technological breakthrough in order to put this in the top spot for any competitive cyclist. More material facts here: [http://www.calfeedesign.com/whitepaper2.htm]

**Economic issues**
The biggest implementation problem with bamboo isn't so much about convincing the consumer that this is a brilliant new material to use for bicycle frame manufacture, but perhaps convincing them to pay the whopping £2000-£2500 for the frame alone. Raw materials are picked in Taiwan's Yushan Park and shipped all the way to California for treatment and production. Although small we can't ignore the fact that these ‘economical’ frames are sent half way across the world by freight, but must realise that 95% of all
other bikes and bike frames manufactured will undergo a large freight journey.

**Consumer/user issues**
The main consumer issues will be as expressed in the paragraphs above; its expense, high-end performance issues and its seriousness. (I mean come on, pandas eat bamboo!) Personally we believe that if it weren't for the existence of carbon fibre in top end bike frames we could have a real contender with the innovative use of bamboo. Unfortunately however, the novelty of a bamboo frame aside, consumers are going to want to purchase a light, responsive bike such as carbon fibre, which not only scores high on its performance, but also on its bling factor. Unless you're a real vintage fan, carbon fibre generally looks better and is more appealing than a bamboo bike.

**Retailer issues**
Again we have the problem of convincing the customer to buy the bike, when there's a perfectly good carbon one sat next to it at quite possibly a cheaper price and a lighter weight. The main retailers will be traders of Bamboo Bikes only such as 'bikebamboo', whereas little trade would occur amongst smaller businesses unless the product became much more globally popular.

**Manufacturer issues**
Manufacturer's will be pleased about the very inexpensive cost of ‘extraction’ of bamboo, but there is still a lot of work required to transfer the raw product into a lean, mean, and environmentally-friendly racing machine. The product must be heated treated and smoked, and 'welded' together using 'hemp fibres'. The process is complicated for manufactures and they have to be 100% enthusiastic to make any real difference.

**Other issues**
Environmentalist issues: Okay so the mass production of bamboo bikes would most definitely result in a reduction of energy used to create other materials such as steel, aluminium, titanium or carbon fibre, but would some people be worried about the large amounts of bamboo that would have to be removed from its habitat in order to satisfy the global demand? Bamboo is the fastest growing plant in the world and generates more oxygen than trees(!) [bikebamboo.com 2010], so the use of this 'anti-global-warming' plant may be considered by some parties as a serious issue.
## Appendices

### Appendix 1: Meeting Review Form

**Meetings Review: Tutor Assessment of Group Activity and Individual Performance Marks**

Case Study Number:
Title:
Group Number:
Group Tutor:

**Meeting 1**
Date:

<table>
<thead>
<tr>
<th>Student</th>
<th>absent</th>
<th>poor</th>
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<th>excellent</th>
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*Comments:*

**Meeting 2**
Date:

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*Comments:*
Appendix 2: Assessment Form

Assessment of Presentations (completed by the tutor)

Case Study Number:                     Date: 
Title: 

Group number: Mark: /10 
Presenters Comments: 

Group number: Mark: /10 
Presenters Comments: 

Group number: Mark: /10 
Presenters Comments: 

Group number: Mark: /10 
Presenters Comments: 

Group number: Mark: /10 
Presenters Comments: 

● Return to case champion
Appendix 3: Peer Assessment Form

Peer Assessment (completed by the students in the group)

Case Study Number:
Title:
Group Number:
Group tutor:
Name:
Individual performance marks:

<table>
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<th>Student</th>
<th>Performance mark</th>
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Notes on individual performance scaling factor
The group will submit one or a number of the following at the completion of a project: a poster, a report, an oral presentation or an html web page. Each part of the submission will be assessed to generate a group mark out of 10. This is scaled by the case tutor to reflect each individual performance with consideration to the feedback from the Peer Assessment Forms completed by all the students at the conclusion of each project.

The individual performance marks should not alter the average mark obtained by the group. Therefore the average of the multipliers must be 1.00. Suitable suggested scaling multipliers are:

- Non-participation: 0.0
- Poor: 0.75
- Average: 1.0
- Good: 1.1
- Excellent: 1.25

Total individual mark = [(report + presentation)/2] x individual scale factor

● Return to case group tutor
Appendix 4: Group Assessment Form

Overall Group Assessment (completed by the tutors)

Case study number:
Date:
Title:
Group number:
Group Tutor:

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<td>Average mark</td>
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Individual marks:

<table>
<thead>
<tr>
<th>Student Name (tutor to complete)</th>
<th>Individual Scale Factor (0-1.25) (tutor to complete)</th>
<th>Total individual mark /10 (champion to complete)</th>
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<tr>
<td>Average value</td>
<td>Average of this column must be 1.0</td>
<td>The same as above average</td>
</tr>
</tbody>
</table>

Notes on individual performance scaling factor
The group will submit one or a number of the following at the completion of a project: a poster, a report, an oral presentation or an html web page. Each part of the submission will be assessed to generate a group mark out of 10. This is scaled by the case tutor to reflect each individual performance with consideration to the feedback from the Peer Assessment Forms completed by all the students at the conclusion of each project.
The individual performance marks should not alter the average mark obtained by the group. Therefore the average of the multipliers must be 1.00. Suitable suggested scaling multipliers are:

<table>
<thead>
<tr>
<th>Level</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-participation (not included in the average for the group)</td>
<td>0.0</td>
</tr>
<tr>
<td>Poor</td>
<td>0.75</td>
</tr>
<tr>
<td>Average</td>
<td>1.0</td>
</tr>
<tr>
<td>Good</td>
<td>1.1</td>
</tr>
<tr>
<td>Excellent</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Total individual mark = [(report + presentation)/2] x individual scale factor

- Return to case study champion
References


Bloom et al., 1956 *Taxonomy of educational objectives: cognitive domain*, New York: McKay


Teaching Materials Engineering: an updated guide


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http://www.qaa.ac.uk/academicinfrastructure/benchmark/honours/default.asp


**Bibliography - other publications you might enjoy**

Accreditation Board for Engineering and Technology Inc (www.abet.org)


Teaching Materials Engineering: an updated guide


Engineering Council UK (www.engc.org.uk)

Engineering Professors Council (www.epc.ac.uk)

European Society for Engineering Education (www.ntb.ch/SEFI)


Institute for Continuing Professional development (www.cpdinstitute.org)

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Kennie, T. Continuing Professional Development: The growing importance of CPD, Institute for Continuing Professional Development (www.cpdinstitute.org)


Race, Phil, (1992) 53 interesting ways to write open learning materials, Bristol: Technical and Educational Services


The Department for Education ([http://www.education.gov.uk/](http://www.education.gov.uk/)) offers a range of immensely informative *Guides for Managers, Practitioners and Researchers* in open and distance learning, commissioned by their Lifelong Learning and Technologies Division. These include many well-documented case studies.


Whyte, W.H., (1956) ‘*The Organization Man*’, Simon and Schuster


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