Inspiring students to create new possibilities for sustainability
INTRODUCTION

Many of our community, lecturers in the disciplines of and relating to Materials Science and Engineering, have expressed interest in simple-to-use guides to support the workshops we run on learning and teaching. As part of our ‘Thematic Groups’ scheme, we have established 12 themes for this special focussed support, each of which is led by a ‘Thematic Group Leader’.

During the first two years of the scheme, workshops have been held on these themes and this has enabled the leaders to further explore relevant issues with lecturers and feed the results into this series of booklets.

Learning and teaching is a continuous cycle represented in the diagram below:

We can start at any point around the cycle. If we are in the business of teaching it certainly helps if there is someone to teach! Not such a funny joke in the current climate with reducing numbers of students in technical disciplines. Hence one of our main concerns is how can we approach schools and work with school students to attract them into Materials areas. ‘Attracting Materials Students’ by Cheryl Anderson explores how we can work with schools and the wider community to ensure a diverse and inclusive group of able students on our courses. Once we have a class to teach, what would we like to teach them? The first reaction to such a question is to make a list of topics or knowledge. However, this is only a beginning, and a very limited one. Not only are there are many skills and attitudes that we
would like them to develop, but learning is more complex than simply the what. It also involves the how. ‘Developing Professional Skills’ by John Wilcox explores the approach to empowering students to track their own skills development as they progress. ‘Materials for Engineers’ by Mike Bramhall, ‘Materials Chemistry’ by Stephen Skinner and ‘Environmental Materials’ by Cris Arnold, focus on what we might like to include in a specialised curriculum, for targeted students. The knowledge, skills and attitudes or learning objectives identified for each course must be assessed if we are going to give credit to students for learning what we want them to learn. ‘Assessing Materials Students’ by Lewis Elton gives support to the development of assessments and assignments that do in fact give marks for those things we want to acknowledge, rather than those aspects that are simply easy to assess!

Believe it or not it is only at this stage that we can really consider how we should teach the students to learn these things. We all know about lectures but will we use in addition or instead: tutorials (‘Tutoring Materials’ by Adam Mannis and Shanaka Katuwawala), labs (‘Teaching Materials Lab Classes’ by Caroline Baillie), case studies (‘Teaching Materials Using Case Studies’ by Claire Davis and Elizabeth Wilcock), problem based learning (‘Learning Materials in a Problem Based Course’ by James Busfield and Ton Peijs) or even learning at a distance (‘Learning Materials at a Distance’ by Mark Endean)?

The final stage before we start all over again is to see if we have done what we intended to do. We may have already found out whether, and how effectively, the students learnt what we wanted them to (i.e. if the assessment matched the learning objectives and if our teaching methods suited the students’ learning approaches). If this has not proved to be as ideal a scenario as we would have wished we will need further input to analyse what has happened. ‘Were the course objectives inappropriate?’ ‘Did the students take on surface approaches to learning because of my teaching?’ Ivan Moore’s ‘Evaluating a Materials Course’ will give you the tools of the trade to conduct your own thorough evaluation and enable you to develop an improved course for next year’s cohort. Which brings us back to the beginning of the cycle. ‘Are we attracting students with appropriate abilities for this course?’ And on it goes ….

In writing these booklets, and running the workshops we have had a lot of fun and we hope that you catch the flavour of this in using them. Stay in touch and give us feedback about your ideas in implementing any of the suggestions. As a community we can learn most from each other.

Caroline Baillie and Leone Burton
Editors
BACKGROUND AND CONTEXT

Issues of environmental protection and sustainable development are gaining an increasing 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 issues, is now subject to environmental considerations. Furthermore, there are many cases where the development of novel ‘environmentally-friendly’ materials are providing new challenges for materials scientists and engineers.

The growing awareness of environmental issues has increased the attention focussed 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 relatively in-depth 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.

This booklet aims to 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 booklet concludes with two case studies which show how these ideas can be put into practice.
OVERVIEW
The figure below schematically shows how the disparate areas under the heading of ‘environmental materials’ can be linked via a life cycle analysis approach.
WHAT TO TEACH

● Life Cycle Analysis

Life Cycle Analysis 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 throughout the cycle.

● Environmental Impacts of Processing

This area often overlaps with the above, and again can provide an interesting slant to the teaching of materials processing. Topics that would come under this subject area include the specific environmental problems associated with processing of metals, polymers, ceramics, composites etc, and how these problems can be overcome.

● Design for Sustainability

This area takes the conventional subjects of materials and process selection and product design and adds the sustainability criterion. It will therefore cover issues such as design for successful recycling, waste minimisation, energy efficiency and increased lifetime.

● Economic, Social and Legislative Issues

Although this subject area takes things outside 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-life vehicle’ and ‘hazardous material’ regulations.

● Use of Sustainable Materials

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 argue against this. It is probably sensible to define such 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.

- **Materials for Green Energy**

  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

- **End-of-Life Issues**

  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.

**HOW TO TEACH**

For students to gain maximum learning outcomes from this area, there is a requirement for a certain amount of basic knowledge. This includes:

- Details of environmental legislation and economic factors
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 multi-media 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
- Self-directed information review
- Market research
- Case-study work

One example of 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 require 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.
ii) Project work can be an even better method for assessing a student’s in-depth understanding and also allow assessment of the student’s ability to devise investigative methods that go beyond the review of published information.

iii) Other methods are also possible within the field of environmental materials, that can mimic real-life situations. For instance, to assess understanding of the legislative issues associated with this subject, mock advocacy case studies could be performed. The development of marketing plans for an environmental material, product or process could also be undertaken.

EVALUATION

In addition to teaching and assessment of learning outcomes, it is important to evaluate the degree to which the learning outcomes have been achieved. For the more factual elements, this is quite simple, based on student’s performance in formal assessments. Project work and extended reports/dissertations give a better indication of how students can gather, assimilate and combine new information. The most important general learning outcome in this area is the ability to generate a complete overview of the inter-relating environmental aspects of a material or process. Assessment and evaluation of such a learning outcome is best made from the more open-ended types of assignments, where students have the freedom to show initiative and their own interpretations.

CASE STUDIES

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.
The main challenges facing the automotive industry at present include:

- End-of-life Vehicle (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. Lightweighting 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.
The second case study also relates to forthcoming waste legislation, the WEEE directive, which will specify 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 will be designated as hazardous and will 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 to be designated as hazardous. The WEEE directive will require minimum levels of recycling of plastics from IT (expected to be about 60%). 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 proven 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:
http://www.environment-agency.gov.uk/business/wasteman

WEEE directive
http://download.lead-free.org/downloads/council.comm_pos.WEEE.pdf

ROHS directive
http://download.lead-free.org/downloads/council.com_pos.RHS.pdf

Environmental Protection Act 1990

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

Guide to Climate Change Levy
http://www.hmce.gov.uk/business/othertaxes/ccl.htm

Guide to Landfill Tax

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

WRAP (Waste & Resources Action Programme)
http://www.wrap.org.uk
Other Booklets In the Series:

- Attracting Materials Students – Cheryl Anderson
- Environmental Materials – Cris Arnold
- Teaching Materials Using Case Studies – Claire Davis and Elizabeth Wilcock

- Developing Professional Skills – John Wilcox
- Assessing Materials Students – Lewis Elton
- Learning Materials at a Distance – Mark Endean

- Materials for Engineers – Mike Bramhall
- Tutoring Materials – Adam Mannis and Shanaka Katuwawala
- Learning Materials in a Problem Based Course – James Busfield and Ton Peijs

- Materials Chemistry – Stephen Skinner
- Teaching Materials Lab Classes – Caroline Baillie
- Evaluating a Materials Course – Ivan Moore
Environmental Materials