Materials Chemistry

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- How will you help them to learn this?
  - DISTANCE LEARNING
  - PBL
  - CASE STUDIES
  - LABS
  - TUTORIALS

- How do you find out if your teaching is useful?

- How will you find out what they have learnt?
  - ASSESSMENT

- What do you want them to learn?
  - PROFESSIONAL SKILLS
  - MATERIALS CHEMISTRY
  - ENVIRONMENTAL MATERIALS
  - MATERIALS FOR ENGINEERS

- How to attract students and who will they be?
  - ATTRACTING STUDENTS

UK Centre for Materials Education
What will you give marks for in the practical?
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
WHY THIS BOOKLET?
Before discussing the teaching of materials chemistry there is a fundamental question that we have to address – what is materials chemistry? Materials chemistry is, for me at least, a subject that covers a wide range of topics and interests – perhaps also including biological and physical dimensions. What has to be defined at an early stage of teaching the subject is what does it mean for you? Once this has been established you can then address the issue of what it should mean for your students. This is something that I will try to address without being too prescriptive towards the content of a materials chemistry course.

This booklet is aimed at lecturers new to materials chemistry. This does not necessarily mean that you are new to lecturing, but that you have not encountered materials chemistry before.

DO YOUR STUDENTS KNOW WHAT MATERIALS CHEMISTRY IS?
This is a critical question as it addresses the students’ expectations of the course you are going to teach. It is likely that the students will know of/recognize chemistry, but what is ‘materials’ and more specifically how does materials chemistry differ from the individual disciplines of ‘materials’ and ‘chemistry’? These are points that should be addressed at an early stage.
In no way can this booklet cover all aspects of materials chemistry teaching, but I will highlight some areas of interest including:

- what is the aim of the course?
- what subject matter should be taught?
- what teaching methods can be used?
- how can learning be assessed?

WHAT CAN MATERIALS CHEMISTRY MEAN?

Materials chemistry can encompass a wide variety of topics ranging from thermodynamics to electrochemistry and crystal defects with excursions into polymers, ceramics and biomaterials.

IS THERE A DIFFERENCE BETWEEN MATERIALS CHEMISTRY AND CHEMISTRY OF MATERIALS?

Both of these terms are frequently used and are generally treated as being interchangeable. A definition of materials chemistry as being the ‘chemistry of all materials’ and the chemistry of materials as ‘being concerned with the chemistry of functional materials’ is useful in understanding the subtle differences between these subjects. Indeed it has been suggested that the main difference between the two is that of scale – bulk properties to a chemist is on the order of 1mm whereas to a materials scientist bulk would be the order of cm and metres. This is further emphasised by the different perceptions of science and engineering, with science viewed as being concerned with microscopic phenomena whereas engineering is about the macroscopic behaviour of materials. Materials itself can be viewed as bridging the ‘language barrier’ between scientists and engineers and materials chemistry is one component of this.

To further complicate matters some degree courses are offered as ‘Chemistry with new materials technology’ which is basically a traditional chemistry course applied to new materials. The list of options is almost endless. How you classify your course will depend on the content of it and the department in which the course is to be taught. It is likely, however, that a materials chemistry course will have some aspect of chemical knowledge and some application or fundamental relationship to an application. It is therefore possible for me to classify crystal defects as a materials chemistry course due to the defect chemistry content and the application to ionic and electronic conductors.

Before developing the materials chemistry content of any course it is important for you to define the context of the material to be delivered within the degree programme.

CONTEXT OF MATERIALS CHEMISTRY WITHIN THE OVERALL DEGREE PROGRAMME

The context of materials chemistry within the overall degree course will determine what is taught, how and to what purpose. Therefore it is important to define if materials chemistry is a core or ancillary component of the degree course. Undoubtedly this will have an influence on the depth of material that can be covered and is therefore crucial in constructing the course to be taught. Another consideration is the level at which the course will be delivered and therefore what level of prior knowledge can you assume.

In considering these issues the main distinction that has to be made at an early stage is whether the course is to be taught to scientists or engineers. Engineers may have little chemical knowledge but may recognize an overlap with some areas of physics that, as a lecturer, can be built on. In
In my particular case the overall degree course is an engineering degree and this defines the units to be taught – primarily physical/inorganic chemistry. However, in the case of an undergraduate course such as ‘Chemistry with new materials technology’ the target audience is obviously chemistry students with the materials as the ancillary component. This issue is critical as it addresses your role within the wider course.

For a module delivered to an outside department (for instance, polymers and composites for medical students) are you engaging the students and maintaining their interest? Given the huge pressure on students how are you going to remain central to the students’ studies? These are issues that are peculiar to outside courses, but maintaining interest is also fundamental in all aspects of a materials chemistry course.

**WHAT ASPECTS OF MATERIALS CHEMISTRY ARE RELEVANT TO YOUR COURSE?**

To maintain interest the issue of what subject matter is relevant and therefore of interest to the student must be considered. Course design is an area that has to be given significant consideration, both in terms of content and presentation.

One of the challenges I have encountered was in addressing an audience with little chemical knowledge – 1st year undergraduates that were only required to have obtained a C grade in GCSE chemistry or double science. How can you teach these students, in 8 hours, effectively a full A-level in chemistry? And how do you ensure that the students have gained sufficient chemical knowledge to proceed to the main degree programme? This preliminary course is critical to the students’ development and understanding of the chemical aspects of a materials engineering course.

In this case the main challenge was in deciding what areas were of importance to the students’ learning of the overall materials degree course. As well as considering the students’ requirements I also had to consider the interdisciplinarity of the course – could I use the students A-level physics knowledge to my advantage? In the early stages of an A-level chemistry course much of the fundamental atomic theory is covered as it is in physics, hence there was no need to cover this for two reasons:

1. **the students had already covered it elsewhere**
2. **repetition of simple material would lose the students’ interest at an early stage**

Furthermore there was no point in going into great detail about organic chemistry and reaction mechanisms as this does not feature in their degree programme. Hence consultation with colleagues as to their expectations of students’ chemical knowledge becomes critical. However, it was also interesting for me to discuss with 2nd and 3rd year students what they saw as being the areas that needed to be covered in order to develop the course further in subsequent years.

**HOW CAN YOU TEACH THIS MATERIAL?**

- What sort of options are available to you?
- Are you aware of all the alternatives?
- What is the best practice for your type of course?
- Can you spend more time covering the material and discussing the content with students by modification of the teaching method?

Whilst using a board may work, the way in which it is used
is critical – try involving the students in the traditional lecture by getting them to think about the material and apply themselves to a problem. Other options may include the use of items such as molecular models which could be particularly useful in the teaching of fundamental aspects of polymers, for example.

Visual aids give a focal point for the lecture and allow you to mingle with the students and interact with them. Further possibilities such as PowerPoint presentations including three-dimensional images, as well as illustrating the lecture allow you to give full copies of material to students. The images given below are generated using freely available software and are used in my preliminary chemistry course in discussions on the structure of organic materials and naming conventions. This means that as lecturers you and I can spend time discussing the material rather than writing everything on a board to be copied religiously by students. Granted this may involve a lot of initial preparation, but the time spent will be worth the end results.

Whilst considering the way in which a course is taught it is also important to consider the learning outcomes for the students in terms of knowledge, skills and attitudes. This feature is significant when considering the objectives for the course. For example, in a course dealing with polymers:

The knowledge based objectives would be of the form ‘to be able to identify functional groups’ or ‘to recognise specific physical properties of polymers’.

In terms of skills you will consider practical abilities, communication of ideas, results and problem solving capabilities.

Attitudes are much harder to define or illustrate but encompass the ‘what is the point of this?’ approach of students. Relating taught material to practical applications may help at this point.

Considering these points may help in determining the approach that you adopt in teaching materials chemistry.
WHAT TEACHING TECHNIQUES CAN YOU USE?

Lecturing is of course only one part of the teaching experience and the techniques applicable to all aspects of the overall course will be relevant to the materials chemistry elements. It is certainly worth considering alternative teaching methods such as problem based learning (PBL). Aspects of a problem based learning approach are dealt with in another booklet in this series. More typically a materials chemistry course, as virtually all science and engineering courses, involves the use of laboratory classes and tutorials. The way in which you utilise these opportunities may well be dictated by the wider constraints of the overall degree course but it is likely that you will want to integrate as closely as possible the various aspects of your teaching through all available methods. In general terms there are a number of methods available for teaching that may be relevant depending on the size of the group of students you are teaching:

- Lectures
- Laboratory sessions
- Tutorials (1-20 students)
- Workshops (> 20 students)
- Peer Tutoring
- Computer Aided Learning Tools

Certain courses, particularly those with a strong theoretical bias, may not lend themselves well to visual aids, but this is an issue on which only you can decide. I find that the techniques that work best for me involve combining the use of the board with some visual aids – for example molecular models and examples of items illustrating the issues associated with certain aspects of materials chemistry. Other colleagues prefer to use an entirely PowerPoint approach with the teaching material then being made available electronically for students. Of course there is a danger that the students will then simply download the materials and not attend the formal teaching sessions. However by careful construction of the lectures these issues can be overcome. It may be that the presentation is used to provide particularly complex diagrams or images to illustrate the applications based nature of the course. The students can then listen to you as a lecturer and annotate their copy appropriately.

This approach works well with courses that have a particularly high visual impact and/or demand – for example biomaterials where the medical implants discussed are most easily described by looking at in-situ images. Another example of this approach would be in the discussion of the structure of materials and in particular the construction of phase diagrams and their relationship to the materials. It is of course feasible that as an alternative to complete electronic access only selected parts of the course are accessible, such as problem sheets, solutions, images and even past examination papers. Further use of electronic media such as the internet allow details of the course to be made widely available. For example the approach used by Lund Institute of Technology, Sweden gives general information on the material covered in each week of the course along with a synopsis and guidelines for the project work. This is obviously making minimal use of the resource but at the other extreme there is the Universite du Maine, France that has a full diploma course available by an electronic distance learning approach.

An interesting complementary form of teaching is peer tutoring. This teaching technique has a number of benefits for students. The concept of peer tutoring is that senior students (3rd/4th year undergraduates) are available during tutorial sessions to assist 1st year students with aspects of the course which is particularly troubling. This has proved
to be extremely valuable in subjects such as crystallography that are very visual and demanding of your time. Obviously the establishment of such a scheme has to be carefully considered and will not be applicable to all areas of materials chemistry but has been found to aid the understanding of all the students involved. Those being tutored gain from the positive experience of discussing problems with their peers rather than staff members. Student tutors gain through a deeper understanding of the material which is essential if they are to explain concepts to their peers in a semi-formal setting. It is also essential in this case that the student tutors are given some training in being the course facilitators. Further details about the use of these teaching methods are available in other booklets in this series.  

ASSESSMENT OPTIONS

What do I mean by assessment options? In this case I will refer only to the assessment of the students’ learning/knowledge/skills and not their evaluation of the course. Typically assessment of students is carried out at the end of a course by some form of examination, usually a written paper. However is it possible that you will need to assess their progress at different times throughout the course? Indeed, in teaching the preliminary chemistry course I give the students a short test at the start of lecture one. The point of this is that it is useful to gauge the level of chemical knowledge throughout the group of students. In this way I can address the needs of the students rather than delivering what I have decided is of importance. As a result I may deliver ostensibly the same material but alter the emphasis of delivery. It is also important at this stage to assure the students that this does not form part of their overall assessment. This then means that the class, typically only a few students, will begin to interact with you and with each other at an early stage in the course. However there are other methods of assessment available that involve the students demonstrating a level of knowledge rather than memory.

A possible scenario illustrating an alternative method of assessing student knowledge would be to set a problem, such as:

**Question:** Identify functional groups of polymers.

Instead of setting a written test/exam consider using a set of molecular models and asking the students to construct simple polymers illustrating the functional groups of interest. This exercise could utilise either traditional models such as those offered by MolymodTM or a computer modelling package, such as ChemDrawTM. It would then be relatively simple to gauge the students understanding of the taught material.

Whilst this is an exercise that could take considerable time and resources to develop, a possibility that requires little extra effort in preparation would be to set a problem that would be applicable over an entire course. For example, a question to be given to the students in an electroceramics course could be:

‘How does a mobile phone work?’

The students would then be given:

- **i:** Clues/keywords at the beginning of the electroceramics course
- **ii:** List of resources including library, lecture notes, web addresses
- **iii:** Report to complete by end of course, perhaps as a press release

As a lecturer the effort would therefore be in ensuring that the material taught included sufficient aspects of mobile phone technology and links between the theoretical aspects taught and the practical application. Further discussion of assessment is available in other booklets in this series.
PRACTICALS/GROUP WORK

An integral part of any materials chemistry course will be lab classes and group work. However practical classes can have very different aims and methods of operation. In designing a lab class it is essential that you determine what you want the students to gain from it. Are you aiming to have the students follow a set procedure to produce a well-defined answer or do they have to apply themselves to a loosely defined problem? Is the main purpose to develop basic chemical skills such as handling equipment and chemicals or is it to apply knowledge to a problem? This will undoubtedly depend on what stage of the course the students are at and the level of staffing available for teaching. Approaches to practical work are covered in detail in other booklets in the series. However there are many options available including case studies and research projects that can be structured as either individual or group work activities.

An example of a case study could be to determine why a coating system had failed and if the failure was chemical or structural. This group work activity would consist of the students being given a sample with a failed coating and access to a number of tools such as SEM, XRD and optical microscopes. Using their knowledge of coatings and the techniques available the students could then determine a plausible reason for failure with a scientific justification. Further examples of practical work could include sending students out on industrial placements and in this case the supervision and assessment of the placements is not trivial. It would be usual to have any project supervised jointly by the students’ home academic and a local industrial supervisor.

Whilst considering aspects of practical work you also have to consider in tandem the assessment of the practical class. Hence the degree of integration between the practical and lecture is of great significance and the balance between the assessment of students’ ability and knowledge requires considerable thought. Is the laboratory experiment a controlled experiment where little knowledge is required or is it an independent study, such as a research project, where student ability and knowledge is more directly tested? These considerations will be influenced by what you are trying to achieve in the laboratory session – a controlled experiment may be aimed at developing practical laboratory skills rather than applying previously acquired knowledge to a problem. Therefore it is important to determine if the practical skills are to be assessed or used as assumed knowledge at a later stage of the course, and you need to consider exactly what will be assessed.

What will you give marks for in the practical?
CAN RESEARCH AREAS BE USED IN YOUR TEACHING?

A great way of achieving student interest in a materials chemistry course is to integrate some aspects of your research interests/achievements into the undergraduate teaching. This can be particularly important where the material delivered is theoretical and therefore fairly dry – for example dielectric behaviour or defect chemistry. Highlighting the applications and the latest advances can inspire students to delve further into the subject area. In one recent case, at the end of a lecture course, I made some remarks about some research I had been carrying out on a new material for solid oxide fuel cell applications. This comment engaged the students more than perhaps any other point of the lecture course and led to an extensive discussion of the work involved.

CONCLUSIONS

Materials chemistry is a wide-ranging subject that can include as many aspects of other sciences as you or your department demands. It is essential that you are clear about what materials chemistry means and the context of the material you are going to deliver. There are many possibilities for delivering the material and assessing both the course and the students. From my experience it will not be right first time but will need to be refined over several repetitions of the course to get the balance and delivery correct.

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8. Teaching Materials Lab Classes, Caroline Baillie, UK Centre for Materials Education, 2003
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