INTERACTIVE SIMULATIONS IN THE TEACHING OF METALLURGY

Peter Goodhew[1], **Andrew Green**[2] **and David Naylor**[3]
[1]University of Liverpool, United Kingdom
[2]MATTER, United Kingdom
[3]International Iron & Steel Institute, Belgium

ABSTRACT

In this paper we describe web-based software which breaks new ground in several ways. The software is designed to enhance learning about two important industrial and commercial materials, steel and aluminium. It is integrated and offers a complex variety of learning routes. The developments of steeluniversity.org and AluMATTER result from collaboration between industry and universities and the software is intended from the outset to be free to users. It arises from the perceived need of industrial employers to demonstrate the complexity of the interaction between materials science and commercial user applications and its importance to their business. It is clearly designed to support the teaching of metallurgy, not to provide a ready-made set of 'lectures' or a complete 'course'. This is an important feature, which encourages adoption of the software, particularly by academics who do not like to be offered someone else's teaching package (the 'not invented here' syndrome).

INTRODUCTION

Over the next few decades, the world will undergo many changes driven by new science and technology and by the needs of society. Industries will increasingly respond to these changes through sustainable developments in process technologies and new products, in order to increase competitiveness, satisfy or even exceed consumer requirements and through initiatives to preserve the environment. In particular the steel and aluminium industries will remain crucially important as providers of strategically important materials.

People are the key to almost every change and given the demographic and technological changes predicted for the metal industries over the next two decades, it is absolutely vital that metal-producing and metal-using companies attract, recruit, train and retain talented people who will become the leaders, managers and technical experts of these businesses in the future. In the UK, university departments of Engineering and Materials Science play a central role in this chain.

The global steel and aluminium industries share major concerns about the decline in the availability of metallurgy or materials science graduates and metallurgy and materials science departments in universities worldwide. Those who study materials science and engineering do not, on graduation, have sufficient in-depth knowledge of metallurgy and in particular, specific alloys such as steel and processes such as casting, rolling and the relationships between processing, microstructure and properties, or products and their applications.

The MATTER team at the University of Liverpool has developed many e-learning resources for metallurgy and materials science (see www.matter.org.uk). Many of these underpin the scientific concepts and tools which are central to materials science, such as crystallography, phase diagrams and microscopy. In this paper, however, two initiatives directly addressed at the needs of the metals industries are described. Both sets of resources are designed to be interactive and are becoming established as key elements of the active learning of students of materials across the world. This paper describes the philosophy behind both these initiatives and illustrates the resources currently available, outline the plans for their further development and illustrate how they are being used and the pedagogical value derived by students and industry employees.

Temperature required: 1530-1540°C

BOF Vessel Tapping Options

You are now ready to start the simulation by 'tapping' the BOF vessel.

At this point, you may wish to add a synthetic slag for desulfurization. If so, use the controls below to select the slag mass and composition.

When you are ready, click on the active vessel to start tapping.

Slag composition: 37CaO, 45Al2O3 (+8SiO2, 1FeO, 7MgO, 1MnO, 1CaF2)

Synthetic slag: 0 kg @ $210/t

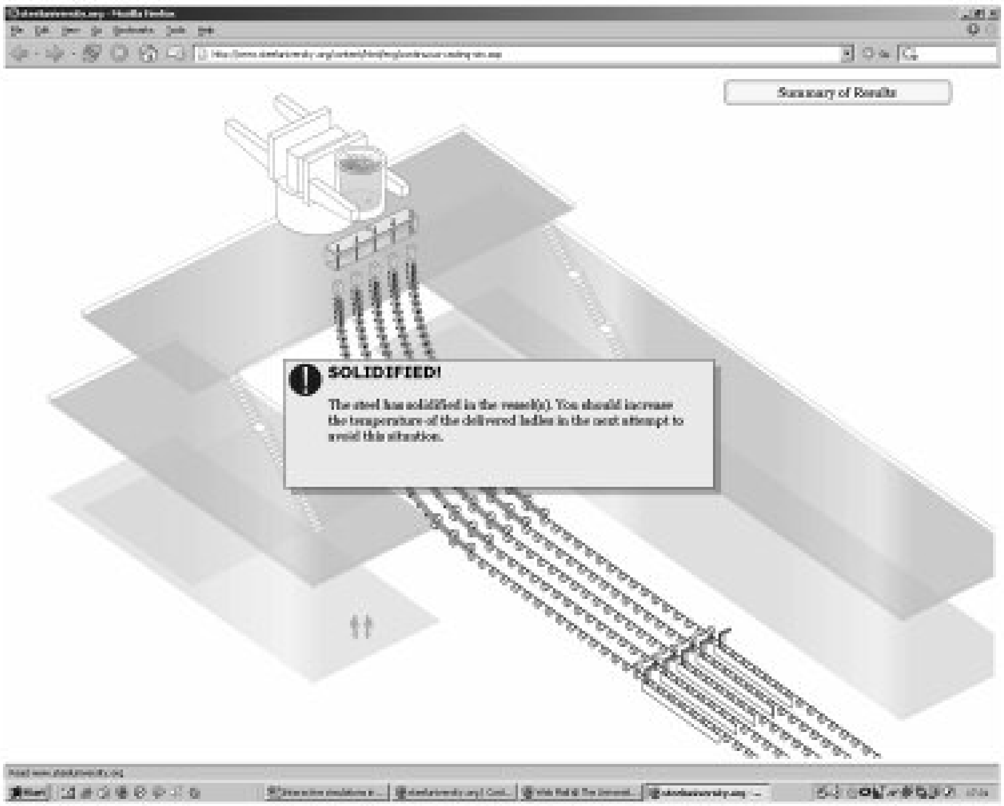
Figure 1: A student interaction point in the Secondary Steelmaking Simulation Exercise

STEELUNIVERSITY.ORG

The International Iron and Steel Institute (IISI) has initiated an innovative, comprehensive, award-winning, highly interactive Internet delivered e-learning resource on steel technologies – http://www.steeluniversity.org. This freely-available website, developed and maintained by the MATTER team, covers steel production and processing, steel products, associated environmental issues and underlying scientific, metallurgical and engineering principles. Its aim is to excite students about steel and attract them to careers in the steel industry, provide industrial applications of metallurgical, scientific and engineering principles for academics and low cost training for employees in the steel industry supply chain.

The core of the steeluniversity.org website is a linked series of highly interactive simulations of the major steelmaking processes from raw materials, through continuous casting, BOF and EAF steelmaking, secondary steelmaking, continuous casting and hot and cold rolling. The learner takes control of a virtual steelworks, making operational decisions, responding to events and seeing the consequences of their decisions in terms of the steel composition, quality and costs, **figures 1 and 2**. Each of these modules can be taken as individual exercises. When completed, it is intended that the learner will be able to process the iron and steel they produce further downstream to a finished product. A certificate is produced at the end of each simulation to provide detailed feedback to the learner, and where appropriate their teacher, trainer and/or mentor, as evidence of what they have achieved. A user guide and more classical supporting e-learning units are also available within each module to enable the learner to better understand the reactions, the application of the relevant of thermodynamics and kinetics. For example, in the secondary steelmaking module, there are sections on deoxidation, desulphurisation, decarburisation and dehydrogenation, as well as slag-metal interactions.

It is intended that these industrial simulations should combine the attractiveness and challenge of a game; goals are set and



SOLIDIFIED!

The steel has solidified in the vessel(s). You should increase the temperature of the delivered ladles in the next attempt to avoid this situation.

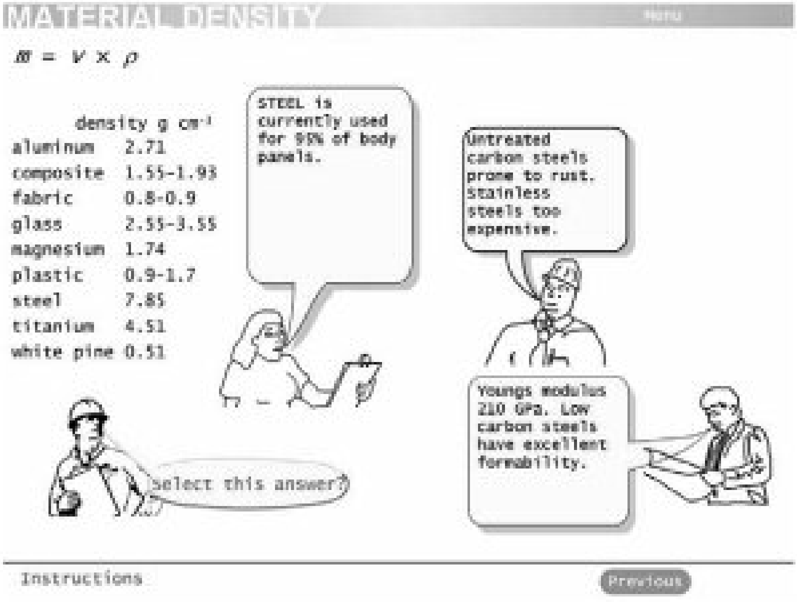
Figure 2: One of the endpoints of the Continuous Casting Simulation

different levels are available, aimed at undergraduate students and graduate employees in the steel industry supply chain. For the latter, operational complications and unexpected events occur that the learner has to cope with and respond as they happen. Realistic models of the steelmaking processes are used to run these simulations: A key feature is that every section of the software has been developed in close collaboration with technical experts from industry and academe.

Other e-learning modules in the steeluniversity.org resource address the selection of steels for different important markets for steel – for automotive and construction applications. In the former the learner undertakes a role-play in which they act as the materials advisor in multidisciplinary team, with the aim of selecting a suitable steel and a design to achieve a 25% weight reduction in a car door panel, **figure 3**. They have a variety of materials to choose from and must also take into account several other factors, including corrosion resistance, formability and weldability, before they are able to select one of today's advanced high strength formable steels which is capable of cost reduction and weight saving and the associated environment benefits. At the end of this exercise, feedback is given on the cost and weight saving made through the decisions made. This software has been used in a materials science module at Liverpool for several years with great success.

Many of these modules are interlinked so that, for example, one of the steels suitable for the lighter weight car door is one of the steels that can be produced in the virtual steelworks.

Another module deals with sustainability and life cycle assessment, drawing on examples from the steel industry and its markets. One of the main goals is to enable the learner to broaden their own view to a life cycle perspective. He/she learns about environmental effects and impacts over the life cycle of steel processes and products, as well as how to influence their sources and to identify the relevant environmental parameters. Therefore the learner will be enabled to explain the basic idea of Life Cycle Thinking and the method of Life Cycle



$m = V \times \rho$

	density g cm^{-3}
aluminum	2.71
composite	1.55-1.93
fabric	0.8-0.9
glass	2.55-3.55
magnesium	1.74
plastic	0.9-1.7
steel	7.85
titanium	4.51
white pine	0.51

STEEL is currently used for 95% of body panels.

Untreated carbon steels prone to rust. Stainless steels too expensive.

Youngs modulus 210 GPa. Low carbon steels have excellent formability.

Figure 3: The project team in the car door material selection exercise

Assessment (LCA), and its practical application. The module includes description and exercises concerning the Goal and Scope definition of LCA studies, Life Cycle Inventory (LCI) and product system modelling, Life Cycle Impact Assessment and interpretation of results from a life cycle study. In addition, the learner can explore selected LCA scenarios facing the steel industry and its customers in the automotive and construction sectors. The commitment of the steel industry to sustainability is reinforced through this resource.

The pedagogical value and quality of the steeluniversity.org resource has been recognized internationally: It was selected as a winner of the European Academic Software Awards 2004, out of over 150 entries. The judges commended the website for its '*Innovative and Excellent Graphical Simulations, Open-Ended Problems and Integrated Educational Approach*'.

steeluniversity.org is already formally integrated into the undergraduate teaching curriculum in several universities in the Austria, Canada, Korea, Netherlands, Sweden, UK(1) and USA. Several steel companies, in Argentina, India and the UK have also formally incorporated it into their graduate training programmes. One has found it to be of value in providing CPD for employees in customer technical support, facilitating solving a customer formability problem. A leading automotive manufacturer has also confirmed that it has also found the resource to be of similar value.

In addition to directed study for individuals and teams, the secondary steelmaking simulation has been successfully used in competition mode for multi-disciplinary teams of graduate trainees in Corus. In December 2005 an international competition to produce a specified grade of steel using the simulations attracted more than 500 entries.

aluMATTER

The European Aluminium Association (EAA) is also developing web-based resources on the metallurgy of aluminium and the associated enabling technologies of forming, joining and machining. These are aimed at students and also employees in small and medium size companies involved in fabricating aluminium products.

aluMATTER (http://aluminium.matter.org.uk) is a freely accessible website, developed by the European Aluminium Association, which aims to provide innovative and interactive e-learning tools for aluminium science and technology. In addition to university students of materials science, engineering and associated disciplines, the site is also aimed at engineers, designers and technicians in small and medium size companies involved in the fabrication of aluminium products. The consortium behind the development of AluMATTER, therefore, includes universities, primary aluminium producers and national aluminium associations.

The following modules had been developed by the end of 2005:

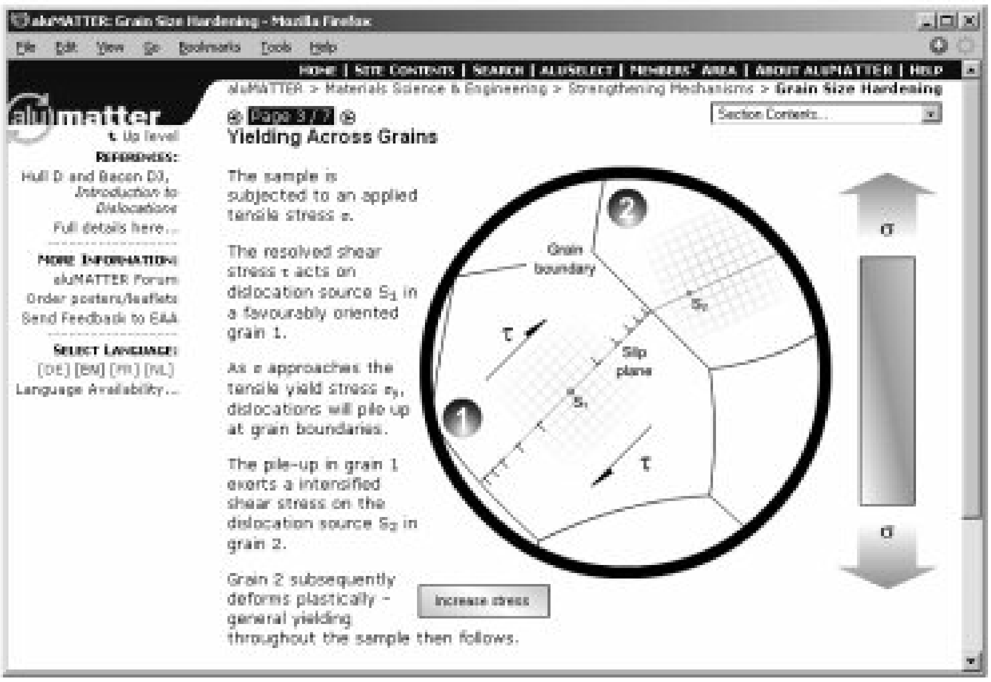
- Strengthening Mechanisms
- Softening Mechanisms
- Anisotropy
- Mechanical Properties
- Surface and Physical Properties
- Machining Technology
- Formability & Forming Technology
- Joining Technology
- Corrosion & Corrosion Control

As in the steeluniversity.org resource, it is possible to access the contents from a starting point of processing, applications or materials science and engineering principles. **Figures 4 and 5** show examples of the treatment of two topics.

PEDAGOGICAL VALUE OF THESE METALLURGICAL E-LEARNING RESOURCES

Both aluMATTER and steeluniversity.org have been designed to encourage student-centred active learning. Their content is informed by expert specialist practitioners, working both in industry and universities, who are in everyday contact with the technical issues. It is the aim that every screen requires the learner to interact thoughtfully with the material – there should be virtually no opportunity to just click 'next' after (or before!) simply reading the screen. The interactive style has been developed over almost twenty years by the MATTER team at the University of Liverpool and has been tested and evaluated with learners from many countries. The range of languages in which the material is presented is intended to encourage use of the software in important steel and aluminium markets, despite the ubiquity of English for technical communication.

It is intended that they be blended (alloyed) into more traditional forms of teaching, learning and training, including formal lectures, tutorials, directed self-study and laboratory classes.



Yielding Across Grains

The sample is subjected to an applied tensile stress σ.

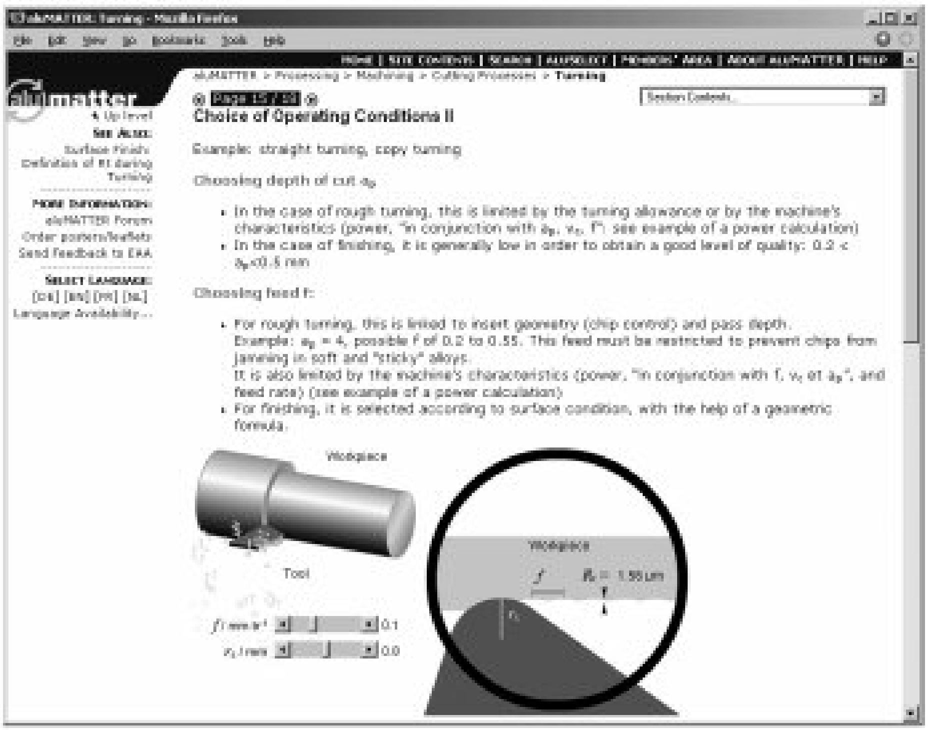
The resolved shear stress τ acts on dislocation source S_1 in a favourably oriented grain 1.

As σ approaches the tensile yield stress σ_y, dislocations will pile up at grain boundaries.

The pile-up in grain 1 exerts a intensified shear stress on the dislocation source S_2 in grain 2.

Grain 2 subsequently deforms plastically – general yielding throughout the sample then follows.

Figure 4: aluMATTER screenshot showing the principle of yielding between grains



Choice of Operating Conditions II

Example: straight turning, copy turning

Choosing depth of cut a_p

- In the case of rough turning, this is limited by the turning allowance or by the machine's characteristics (power, "in conjunction with a_p, v_c, f": see example of a power calculation)
- In the case of finishing, it is generally low in order to obtain a good level of quality: $0.2 < a_p < 0.5$ mm

Choosing feed f:

- For rough turning, this is limited to insert geometry (chip control) and pass depth.
  Example: $a_p = 4$, possible f of 0.2 to 0.55. This feed must be restricted to prevent chips from jamming in soft and "sticky" alloys.
  It is also limited by the machine's characteristics (power, "in conjunction with f, v_c et a_p", and feed rate) (see example of a power calculation)
- For finishing, it is selected according to surface condition, with the help of a geometric formula.

Figure 5: Screenshot from the aluMATTER Machining module, showing the effect of workpiece radius and feed on the surface condition

An example of the constructive use of this type of software is a second-year module in the Department of Engineering at the University of Liverpool which is built around two exercises: Half of the time is committed to a 'Manufactured article' exercise – effectively a reverse engineering task – while the other half is devoted to a material selection exercise for a car door.

The 'car door' exercise is delivered in a traditional PBL (problem based learning) environment(2,3) over seven weeks, with the weekly group meetings taking the form of formal minuted committee meetings with an agenda and chairperson. All student group activities are designed to simulate problem solving within an industrial environment. In this context the University's virtual learning environment is reconfigured to become the intranet for the 'Virtual Steel Company' that employs the students, and tutorial support is available via financially limited email access to the Virtual Steel Company's expert consultants (actually two of the academic staff) each week. The PBL 'problem' links directly with fictitious minutes of the 'Virtual Steel Company' Board and other resources. It has been carefully designed to require students to work through the car door steel selection exercise on the steeluniversity.org site and other real technical information accessible only via the web. This module allows for the detailed study of steel selection and processing via interactive simulations, supported by experimental activities and data. The whole exercise is supported by visits to a steel works and a car manufacturer, but it is designed to be a real-world important current industrial problem, impossible to solve without access to the interactive software(1).

Assessment of the PBL exercise has three elements; there is an individual test of technical learning outcomes, a written executive group report, and a group oral presentation, with the latter two being peer moderated within each group.

Although this is the first experience most students have had of PBL, and staff notice it takes 4 or 5 weeks until students focus and identify the important issues, feedback indicates an almost unanimous preference for PBL teaching. Students also find that the formal professional structured approach to meetings (agenda, minutes etc) helps them to focus and identify the key issues involved. The peer moderation process is also unanimously favoured, particularly when ‘ideas’ and ‘leadership’ moderation criteria are included alongside ‘effort’ and ‘time’.

A major series of applications of steeluniversity.org is planned for 2006 and 2007. Tenaris (a major steel company based in South America) is supporting the introduction of the teaching of steel into six universities in Argentina. In each institution a well-structured set of exercises has been agreed with the teaching department and is to be carried out typically twice per year. Each set of exercises will involve:

- Guided reading of three selected chapters from the books recommended on the steeluniversity.org site;
- Student-led experimentation with the software and simulations, followed a few weeks later by:
- A four-hour intensive hands-on course conducted by experts from the steel industry, followed three to four weeks later by;
- A competition among the students at that specific institution, the winner of which will compete with the winner from the other five institutions. The form of the competition will be similar to the international competition run in 2005 (referred to above).

Key features of these programmes are that the learning is truly ‘blended’ with a mix of paper-based resources, e-learning and the element of competition. The periods of a few weeks between the different phases are deliberately introduced to allow for assimilation of the concepts and practice with the simulations. Feedback from these structured sessions will be reported in a future paper. A slightly extended version of the same set of exercises is also being used with young steel company professionals.

CONCLUSIONS

The web-based software described in this paper breaks new ground in several ways. It is integrated and offers a complex variety of learning routes. It results from collaboration between industry and universities and is intended from the outset to be free to users. It arises from the perceived need of industrial employers to demonstrate the complexity of the interaction between materials science and commercial user applications and its importance to their business. It is clearly designed to support the teaching of metallurgy, not to provide a ready-made set of ‘lectures’ or a complete ‘course’. This is an important feature, which encourages adoption of the software, particularly by academics who do not like to be offered someone else’s teaching package (the ‘not invented here’ syndrome). Development of both steeluniversity.org and aluMATTER is continuing.

ACKNOWLEDGEMENTS

We would like to thank Marina Christin of Tenaris for telling us of the activity in Argentina.

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REJUVENATION OF ENGINEERING LEGACY COMPUTER BASED LEARNING MATERIAL BY REPURPOSING INTO LEARNING OBJECTS

Barry J. Beggs, Elaine M. Smith and Allan J. Pellow
Glasgow Caledonian University, United Kingdom

ABSTRACT

There are many examples of excellent computer based learning (CBL) materials which have been developed over the years under funding from programmes such as the Teaching and Learning Technology Programme (TLTP). These resources have found a place in the teaching and learning environments of numerous educational establishments. Most resources of this type were created prior to the more modern approach of producing Learning Objects (LOs). The work reported in this paper is based on a project which aims to rejuvenate the usefulness of high quality legacy engineering and mathematics CBL resources from previous projects by re-engineering the original monolithic packages into more granular, stand-alone LOs which will be made available to the academic community through the Joint Information Systems Committee (JISC) LO repository known as JORUM.

INTRODUCTION

There have been many content producing initiatives and programmes, such as the Teaching and Leaning Technology Programme (TLTP)(1), which funded the development of several large scale packages relevant to the teaching of science, engineering and technology. Many of the packages produced by these initiatives comprised materials aimed at first year university programmes, HND, HNC and Foundation programmes. The EASEIT-Eng(2) project, which carried out evaluations of CBL materials being used in UK HE Engineering programmes, found that many engineering TLTP packages (and similar resources of the same age) are still being actively used in spite of their age. Teachers using these packages reported that the underlying pedagogy and subject coverage of the resources was sound, however their usefulness was inhibited by factors that include:

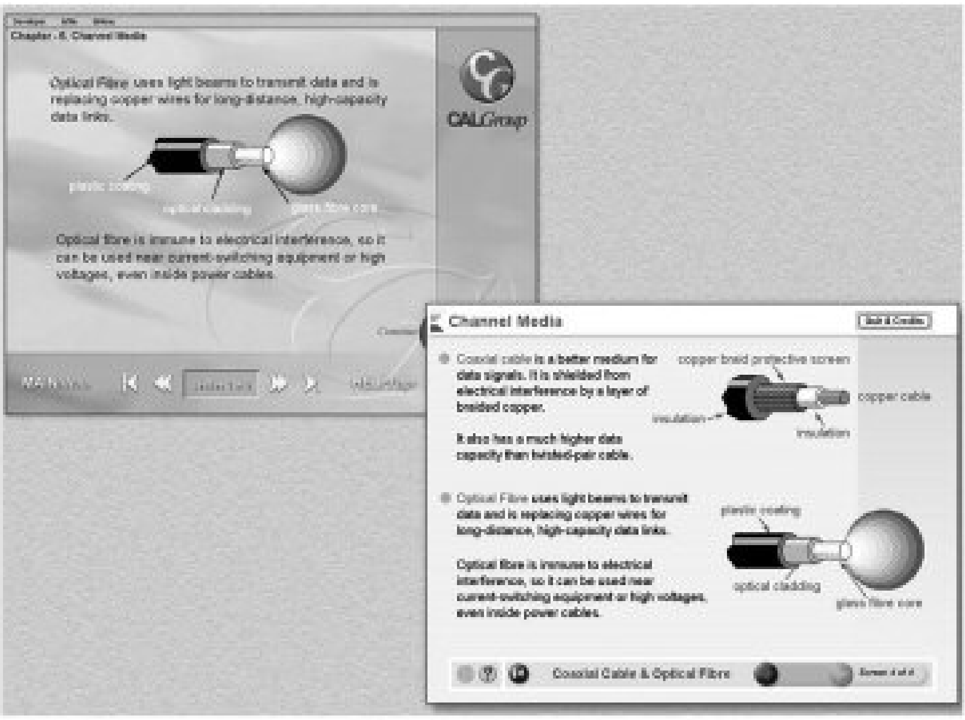
- The age of the software, which often required out of date hardware and supporting software in order to run;
- The material was locked into monolithic packages;
- The material was difficult to integrate into VLEs;
- The teacher could not adapt the material;
- Accessibility issues are not addressed.

By dealing with the five points above, the re-purposed learning materials produced by the ReSET(3) project will have increased value, improved accessibility and will become widely available through JORUM(4) for access by UK academic institutions.

THE ReSET PROJECT

The JISC Exchange for Learning Programme (X4L)(5) has funded a large number of projects in two phases in recent years. The JISC X4L Phase 2 funded project being described in this paper is called ReSET. The ReSET project runs from early in 2005 until summer of 2006. The work of ReSET involves the re-engineering of existing, high quality computer based learning resources into state-of-the-art, international standards compliant Learning Objects. Re-purposing and adapting existing CBL resources promises many benefits over the alternative of creating completely new Learning Object content including:

- The resources have already been quality assured and reviewed (through peer review or similar mechanisms);
- Reuse is more cost effective than creation of new content;
- Alternative or additional elements can be created to supplement existing content.



Optical Fibre uses light beams to transmit data and is replacing copper wires for long-distance, high-capacity data links.

Optical fibre is immune to electrical interference, so it can be used near current-switching equipment or high voltages, even inside power cables.

- Coaxial cable is a better medium for data signals. It is shielded from electrical interference by a layer of braided copper.

  It also has a much higher data capacity than twisted-pair cable.

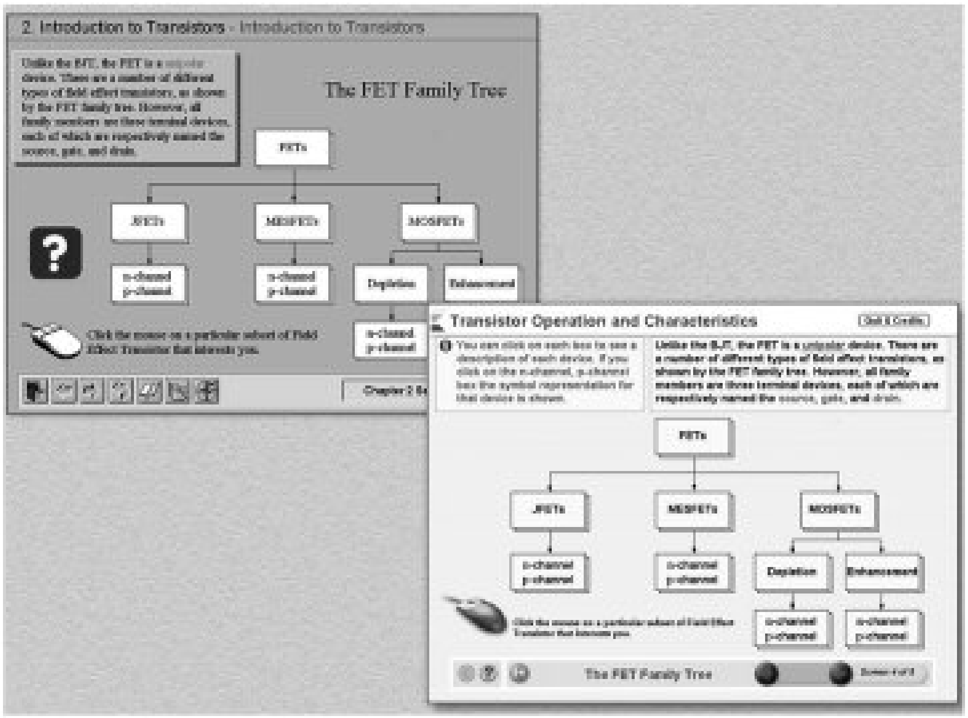
- Optical Fibre uses light beams to transmit data and is replacing copper wires for long-distance, high-capacity data links.

  Optical fibre is immune to electrical interference, so it can be used near current-switching equipment or high voltages, even inside power cables.

Figure 1: Original CALgroup screen and ReSET Learning Object version

Historically, the reuse of CBL resources has been difficult to realise since the resources are difficult, or impossible, to use in any context other than the one for which they were designed. Teachers are, understandably, unwilling to tailor their programmes to suit the available resources simply because certain resources exist. This is a particular problem in Higher Education (HE) where there is no uniformity of content in syllabi. An approach to enhancing reusability of existing CBL materials, in which there has been very heavy investment of funding and time, is to provide such resources as Learning Objects. There is no consensus on a precise definition of a Learning Object. For the purposes of this paper, we define a Learning Object as being a unit of learning material large enough to be pedagogically meaningful, e.g. one comprising enough material to address at least one learning objective and which is capable of being delivered to the learner electronically. A number of such Learning Objects can be compiled into a bespoke learning experience by lecturers for their students to use. A learning experience in this context could be many things such as an online lesson, a pre-assessment self-study session, a laboratory exercise, a presentation for use in a lecture or others. Learning Objects must be relatively ‘granular’ material which is well described (by metadata) and which conforms to reusability standards such as those produced by the IMS Global Learning Consortium(6). If LOs are well-described and catalogued, they can be readily stored in, and retrieved from, online repository systems such as JORUM.

Many of the benefits promised by the existence of Learning Objects are dependent on two things. Firstly, there needs to be a reasonable quantity of LOs available so that teachers may choose from a good range of suitable elements. Without this choice, aggregating Learning Objects into a learning experience is merely a less convenient way of obtaining large units of inflexible courseware. Secondly, teachers need to be skilled at choosing and reusing this type of resource so that they can select the most appropriate Learning Objects and tailor the end product to the needs of their students. It is the first of these two areas that the ReSET project aims to address by fragmenting existing high quality monolithic CBL resources into smaller segments and packaging these smaller sections as LOs for deposit into JORUM.



Unlike the BJT, the FET is a unipolar device. There are a number of different types of field effect transistors, as shown by the FET family tree. However, all family members are three terminal devices, each of which are respectively named the source, gate, and drain.

Figure 2: Original EDEC screen and ReSET Learning Object version

THE CONTENT BEING RE-ENGINEERED

The ReSET project is a consortium of Universities, Colleges, former CBL projects and Higher Education Academy Centres. Four former CBL producing projects are providing content, EDEC(7), CALgroup(8), HELM(9) and MATTER(10). EDEC produced resources suitable for advanced level study of electronics. CALgroup produced more introductory resources in a number of engineering disciplines. HELM produced resources specifically to help engineers with learning mathematics. MATTER produced resources for the study of material science. During the 18 months of the ReSET project, over 200 LOs will be created from the above original legacy sources. These LOs will be deposited in the JISC JORUM repository ready for use by the start of academic year 2006/7. Even although this appears to be a large number of LOs, a very substantial body of the excellent legacy content will remain untouched by the project due to resource limitations. It would be a great loss if no way could be found to ensure that the remaining legacy content is also re-engineered in the near future.

THE APPROACH TO RE-ENGINEERING

One of the first, and most challenging, tasks undertaken has been the identification of sections of content that can be considered to be suitable as LOs. In many respects this is a matter of academic opinion and there will never be full agreement on such decisions. In some cases a single screen of content has been selected as a LO and in other cases it has been appropriate to create a much larger LO from multiple screens involving user interactions, animations, simulations, etc. The majority of the legacy content was created in the Macromedia Authorware environment and it was decided to perform the re-engineering in this environment also. One minor technical issue was that some content had been created in very early versions of Authorware and multi-stage conversion was required in order to bring the content to the current version of the environment. Since the content being worked on is from four different authoring teams, the appearance and style of presentation is very different. It was decided to have a simple, universal style and presentation for all re-engineered LOs and this was done in a way that would be fairly neutral but still be attractive to users. **Figure 1** and **figure 2** show the original and new versions of typical screens from CALgroup and EDEC respectively.

Although there was no need to change the academic content of the legacy material, there were a number of very important changes which had to be made in order to bring the appearance and usability up to date. The methods of navigation had to be standardised and made as simple as possible. In many cases, the use of colour had to be carefully studied to ensure that there was clarity about the meaning of various colours. One key example of this was the previous occasional use of blue text for simple highlighting purposes which could nowadays be interpreted as being some type of hyperlink. A number of other accessibility issues were also dealt with in relation to features such as selection of type of font, font size, appropriate use of colour and complexity of screen design.

On completion of the re-structuring of the content into segments suitable for use as an LO, the ReLOAD(11) software tool was used to package the content into the format required to allow it to be uploaded to JORUM for general use.

USING THE LEARNING OBJECTS

LOs can be downloaded from JORUM and used in various ways. They may be useful in some cases simply as sources of content to be inserted into lecture presentations. A more sophisticated approach is to use a tool such as the Learning Design Editor from the ReLOAD team(11) or the Learning Activity Management System(12) to combine a range of LOs, and possibly other resources, into a stand-alone learning activity or incorporated into a format suitable for delivery via one of the commonly used VLEs.

Although we are still at an early stage in the evolution of Learning Design and the use of Learning Objects, as the number of LOs available increases there will be more opportunity for enterprising academics to experiment with this exciting new way of creating innovative learning environments for use by students.

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DEVELOPMENT OF A VIRTUAL LEARNING ENVIRONMENT TOOL FOR FIRST YEAR STUDENTS TAKING MATERIALS SCIENCE/ENGINEERING MODULES

Tahar Laoui and John O'Donoghue
University of Wolverhampton, United Kingdom

ABSTRACT

This paper is based on the experience acquired in teaching materials science/ engineering to first year university students. It has been observed that students struggle with some of the fundamental materials concepts addressed in the module/course. This applies to delivered lectures but extends to the incorporation of tutorial sessions provided after lectures. Moreover, when students miss a lecture or seminar the acquisition and application of knowledge and concepts becomes problematic. Consequently, or perhaps inevitably, these students perform poorly in their assessments and their motivation for the subject suffers.

A careful analysis of this situation and of the nature of interaction and engagement was performed to gain an insight into the reasons for this lack of performance. A common factor is that students do not dedicate sufficient time for (background) reading and consolidation using the chapters/sections prescribed after each topic and/or do not attempt solving tutorial problems outside the contact hours. This reflection and personal evaluation is difficult to administer, resource intensive and yet potentially enables each student to monitor and evaluate their own learning and understanding.

PROJECT DESCRIPTION

Reason for undertaking this project

The first author has been involved in teaching the module ‘Materials Technology 1’ delivered to level 1 students for the last five years at the School of Engineering & Built Environment, University of Wolverhampton. It was observed that a number of students struggle with some of the materials’ concepts given in this module. Moreover, some students miss a few lectures creating a problem in their establishment and consolidation of the knowledge and concepts that are given in successive presentations and lectures. Consequently, these students perform poorly in their assessments and some of them even fail the module.

A careful analysis of this situation was performed to gain an insight into the reasons of this poor performance. A key reason found to be a common factor for most of the students to different extents, is that these students do not dedicate sufficient time (or even no time for some students) for (background) reading the chapters/sections prescribed after each topic and/or do not attempt solving tutorial problems outside the contact hours. They also failed to apply the knowledge acquired from their reading into the environments and situations located within the subject.

Aim of the Project

This aim of the project was to develop a virtual learning environment (VLE) tool utilising technology, which would enable the students to develop their skills, acquisition and application of knowledge as well as to achieve their learning outcomes at a self-determined autonomous independent level. The desire was to achieve a much ‘deeper’ approach to learning(1) linked intrinsically to the learning outcomes of the module. Ramsden(2), interpreted and refined this approach whereby students adopted a strategic approach to their learning i.e. they, the students, are concerned to get the best possible grade and this may involve both a surface approach and a deep approach to learning, depending on the nature of the task. It was in this context that the development progressed. So whilst the focus was on achieving a successful assessment outcome, the creation of the media within the VLE was targeting the understanding and application of the subject.

Learning outcomes

Whilst the rationale was 'remedial', reinforcing and potentially at a higher cognitive level (3) than what was delivered within the lectures, the objectives had to be clearly aligned with the learning outcomes. The learning outcomes of this first year materials science/technology module are:

Subject Specific

a) Classify engineering materials in terms of their generic groups and general fields of application based on their properties.

b) Appreciate the factors controlling properties and the interrelation between properties and microstructure and how properties can be modified by changing structure.

Intellectual Skills

c) Apply knowledge and understanding

Key Skills

d) Apply/use numbers (mathematical equations)

METHODOLOGY

The programme of study of Materials Technology 1 has been via lectures and laboratory experiments. The outcome of this project will not completely replace these, but will enable the students to develop their skills, knowledge and achieve their learning outcomes at a self-determined independent level. Although learning through exploring problem situations is not new, problem-based learning was popularised in the 1960s as a result of research by Barrows and Tamblyn into the reasoning abilities of medical students(4). The ability to individualise the learning experience via a VLE approach for each student is very exciting.

The project will draw upon the main themes of the problem-based approach from Duch(5).

1. An effective problem must first engage students' interest, and motivate them to probe for deeper understanding of the concepts being introduced. It should relate the subject to the real world, so that students have a stake in solving the problem.
2. Good problems require students to make decisions or judgements based on facts, information, logic and/or rationalization. Students should be required to justify all decisions and reasoning based on the principles being learned. Problems should require students to define what assumptions are needed (and why), what information is relevant, and/or what steps or procedures are required in order to solve them.
3. Cooperation from all members of the student group should be necessary in order to effectively work through a good problem. The length and complexity of the problem or case must be controlled so that students realize that a 'divide and conquer' effort will not be an effective problem-solving strategy. For example, a problem that consists of a series of straight-forward 'end of chapter' questions will be divided by the group and assigned to individuals and then reassembled for the assignment submission. In this case, students end up learning less not more.
4. The initial questions in the problem should have one or more of the following characteristics so that all students in the groups are initially drawn into a discussion of the topic:

- open-ended, not limited to one correct answer
- connected to previously learned knowledge
- controversial issues that will elicit diverse opinions

Detailed methodology

- An individual account was set up in the VLE of the university (WOLF) for all registered students taking this module 'Materials Technology 1'.

- Lecture notes containing the power point presentations (delivered during regular weekly classes) were made available for the students via VLE using a password specific to each student.
- Animations were incorporated into the lectures to visualise some phenomena related to the concepts to help student gain a better grasp and understanding.
- Students were involved in forums and discussion with their respective peers and lecturers/tutors to discuss the effectiveness of this innovative approach to teaching and learning.

EXAMPLES OF THE ANIMATED MATERIALS

The first part of this VLE tool addresses the concepts related to the description of the atomic model structure, atomic bonding, crystal structure and imperfection in solids. **Figure 1** displays a couple of snap shots obtained at different stages of this VLE tool showing a 3D animated atomic model with three energy shells providing explanations in form of windows containing additional information. By clicking inside the model, the internal 'nucleus structure' opens up revealing the protons and neutrons. The tool contains several windows including (menu) giving access to all individual screens, (presentation) allowing the display of the first screen showing the 3D animated atom model, (www) providing links to relevant websites for additional reading.

The periodic table is also well addressed in the VLE indicating how the elements are positioned in the table as well as how to determine correctly the electronic structure of any atom by putting the electrons in their proper energy levels (**figure 2**).

Figure 3 displays a simulated 2D and 3D models containing an imperfection (an edge dislocation) with animation to show the movement of the extra half plane due to applied shear stress and the associated local regions under tension and compression.

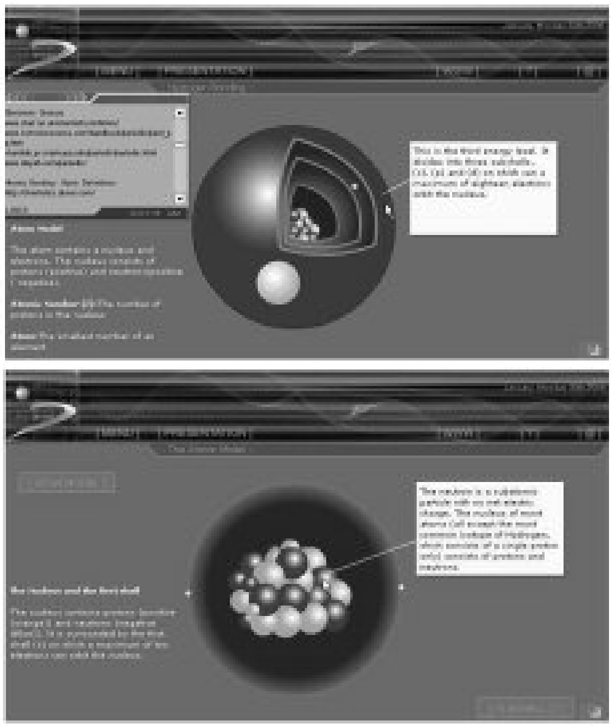

Figure 1: A 3D animated atomic model shown with three energy shells/levels providing explanations in form of windows containing additional information

EVALUATION STRATEGY

The project impact was initially evaluated via student discussion in the computer lab connected with WOLF when the module was delivered in 2005 & 2006. Students were involved in forums and discussion with their respective peers and lecturer to discuss the effectiveness of this innovative approach to teaching and learning. The students were very excited and showed considerable enthusiasm. Whilst appreciating that some of this enthusiasm may be due to the novelty effect, or 'Hawthorne' effect, the use of a multimedia approach was both thought provoking (for the students) and established concepts and structures at a much deeper level of understanding.

In mapping the activity to Saljo's distinct conception of learning(6), the lectures and seminars clearly addressed the first three levels. Via the VLE development, this acquisition and application of knowledge was extended into levels 4&5 (abstraction and interpretation). This was enabled via the animation and simulation provided by the

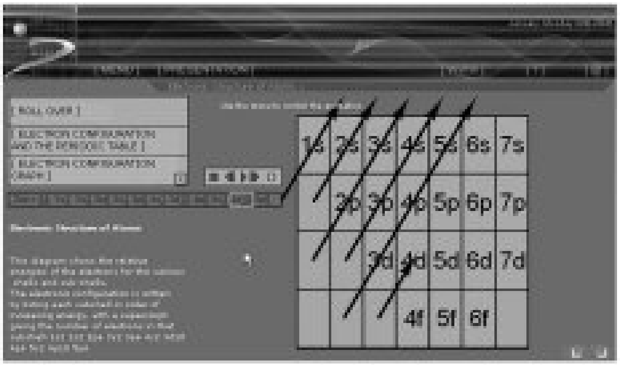

Figure 2: An animated screen allowing the student to position correctly the electrons around an atom (example of Xenon is displayed)

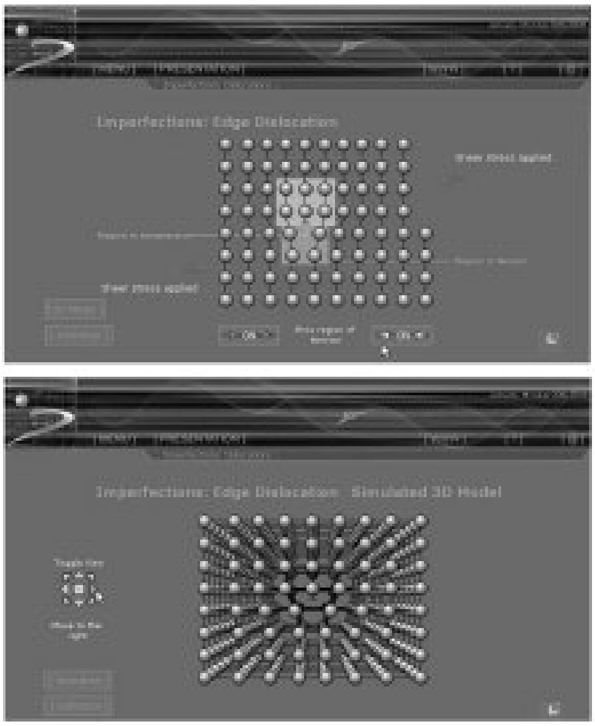

Figure 3: A simulated 2D and 3D model containing an imperfection (an edge dislocation) with animation to show the movement of the extra half plane due to the applied shear stress

media i.e. a new learning environment enables an insight into the subject, which can then be transferred across and between other domains. Again, as already intimated, the engagement was targeted at what Bloom(3) calls the analysis, synthesis and evaluation phases of cognitive development. Holistically the lectures provided an introduction, extended into the supporting VLE, and then further extrapolation by the students. All this clearly aligned to the learning outcomes.

Further evaluation from students was gathered through an anonymous online questionnaire, which was available for all the students registered on the module (2006). The questionnaire consisted of fifteen questions including both closed and open-ended questions in order to furnish quantitative and qualitative data. Six questions were used to ascertain the extent, nature and reach of the use of the multimedia content of the VLE in supporting, extending and reinforcing understanding of the more formal lecture materials and complex theories. There were three questions aimed at understanding the students' engagement with the content and their increase in motivation as a consequence of both engagement and understanding. Finally, there were seven open questions, which asked about transferability of understanding, use in other areas, positive and negative issues, areas that might require improvement, and suggestions for additional functionality.

The group of respondents numbered 25. Whilst as a representative sample of students this is small, in terms of the module it represents a 75% return. The evaluation demonstrated a significant appreciation and a welcoming for using this mode of study, i.e. lectures further supported and enhanced by alternative online media approaches which students can study and engage with remotely and at their own pace. The overwhelming percentage of students felt that they understood the concept of atomic structure as a consequence of the animations within the VLE – '*that this type of approach be implemented to other subjects so students can gather a better understanding of the lecture from another perspective in a less complicated view', 'the main strength of the VLE project is that I can review the stuff covered in lectures and the parts I didn't understand so well I can go through them at my own pace'*.

All the students who submitted responses felt that their understanding of the concepts related to the materials covered in the lectures had improved as a direct consequence of the VLE. What was most interesting is that a significant number of students would welcome additional formative assessment as part of the VLE project to test their understanding at each stage, i.e. '*more self-assessment questions would be appreciated to gauge yourself on how much you understand the concepts or short tutorial questions with solutions given at the end', 'to improve, I think if tutorial questions were to be increased, with solutions given at the end, it would help the students to self assess themselves*.'

An attempt was made to elicit the students' perceptions of the nature and the value of their engagement and understanding of the VLE content. In particular, did the engagement foster a deeper approach to study(7)? This is difficult to assess in such a small study. Certainly the understanding and application of the concepts and structures in other domains will be assessed via other modules and against groups hitherto not exposed to this project.

FUTURE WORK/DEVELOPMENT

It is planned to develop a flowchart centred around a simulation, with multiple routes, through which the student can traverse. It will include video footage of experimentation e.g. tensile testing as well as animations exploring what is physically/conceptually happening at various stages. Students can be directed to physically conduct experiments as well as visualise what is taking place via the VLE. At various stages, there will be an opportunity for formative assessment to assess what the students have engaged in and what has been learnt as a consequence (based on the learned concepts through the given lectures/practical sessions and the requested background reading). In addition to individual pathways, students will be able to become involved in forums and discussion with their respective peers and tutors.

ACKNOWLEDGMENTS

The authors would like to gratefully acknowledge the grant of UKCME – UK Centre for Materials Education – used to carry out part of this project.

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USE OF FINITE ELEMENT MODELLING IN MATERIALS TEACHING

Xuejun Ren, Lisa Li and Glynn Rothwell
Liverpool John Moores University, United Kingdom

ABSTRACT

Finite element modelling (FEM) is a powerful tool for simulating the behaviour of materials or structures under different loading situations. Use of this technique can potentially make materials teaching more interesting and informative and help students to understand the link between materials, manufacture and design. In this work the use of FE simulation for materials teaching was studied using specially designed lectures and coursework in both materials engineering and sports technology modules. Results showed that the analysis and visualisation functions of FEM made the teaching more interesting and informative. Simulation based coursework had a significant effect on the learning behaviour of the students and encouraged deep learning and teamwork. FEM modelling facilitated class interaction and made it easier to set individual tailored coursework without incurring high cost or marking load. The impact of using FEM on both teaching and learning is discussed and guidelines in using the method are given.

INTRODUCTION

The study of materials bridges many 'pure' disciplines, such as physics, chemistry, mathematics etc. Engineering schools include and value the teaching because engineers make things, and they make them out of materials (Ashby *et al*[1]). It is important to make programs of study interesting and accessible to mechanical engineering students at different levels. In product development type processes, the students are increasingly being required to have integrated knowledge combining materials, design and the manufacturing process (Ward(2), Dym *et al*(3), Prasad(4)). However, with the diversity of modern materials, the integration of materials, manufacture and design (**figure 1**) is difficult to achieve in a conventional way. A more informative and interactive method is required.

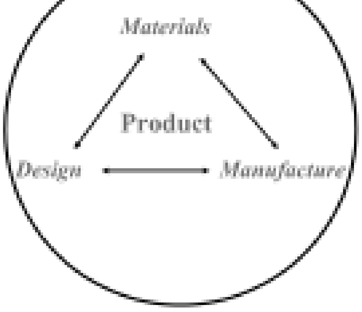


Figure 1: Materials teaching in engineering education

Finite element modelling is a very powerful tool for simulating the behaviour of materials and the effect of material properties (e.g. mechanical, thermal or electrical) under different loading conditions (Fagan [5]). It has been widely used in mechanical engineering education as a simulation tool for both solid or fluid problems (Guessous *et al* [6]) but the systematic use of FEM in materials teaching is limited.

In this work, FE modelling has been used as an integrated part of material teaching and its impact on teaching and learning assessed. The main procedure in an FE modelling process and its potential benefits to the material teaching are analysed. Two typical applications of material processing and design are presented to demonstrate the use of FEM in preparing lectures, tutorial and coursework. The impact of FEM on student learning has been evaluated using questionnaires and peer review. The benefits of FEM in materials teaching and potential difficulties in implementing this method are discussed.

POTENTIAL BENEFITS OF FEM IN MATERIALS TEACHING

As shown in **figure 2**, the FE simulation process

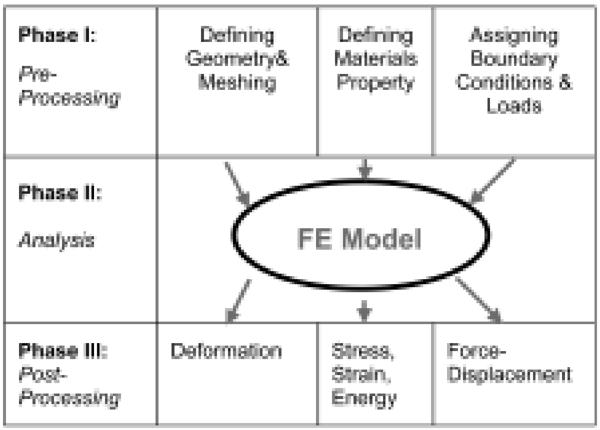
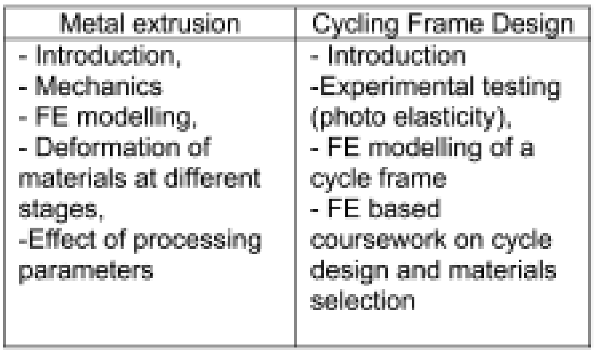


Figure 2: Main steps of the finite element modelling



Metal extrusion	Cycling Frame Design
- Introduction, - Mechanics - FE modelling, - Deformation of materials at different stages, -Effect of processing parameters	- Introduction -Experimental testing (photo elasticity), - FE modelling of a cycle frame - FE based coursework on cycle design and materials selection

Table 1: Main activity for the two case studies

consists of three main phases: pre-processing, analysis and post-processing. The main focus of activity in the pre-processing phase includes constructing and meshing the model, applying the boundary and loading conditions and assigning the material properties. The analysis phase involves mathematically solving the equations for all the elements and the global system equations. Once the model has been solved, the behavior of the material/structure of interest can be plotted/listed using a variety of methods (e.g. contour plot, vector plot, animation, etc.), which provides much more in-depth information than videos, or photos. FEM can show both internal and external fields, such as non-uniform displacement fields, stress and strain distributions etc.

As shown in **figure 2**, FE simulation covers the major aspects of design and material behavior and can be used to teach material properties, material processing and design in an integrated way that would be difficult to achieve in a conventional way. For example, in materials processing modules, students have difficulty linking material properties (e.g. yielding, work hardening, etc.) to their manufacturability. Similarly, when learning materials selection in mechanical design, there is clearly a need to assess the potential impact of material choice on the performance of the product. However, there is no quick and effective tool to put student thinking to the test. These difficulties can be easily overcome if the teaching/learning is facilitated with FEM. In modern versions of most of the FEM software (such as ANSYS, ABAQUS, etc), users (experienced or inexperienced) can easily change the parameters of interest in the program such as material properties to compare their effects. This makes it technically feasible to use FEM modelling in materials teaching without going through a lengthy learning process of the software itself. In addition, current engineering students are well trained in computation and dealing with new software, this will also help to achieve the full benefit of FEM.

USE OF FEM IN TEACHING MATERIALS PROCESSING AND MATERIALS SELECTION

FE has been systematically used in the preparation of lecture notes, tutorials and coursework. The modules involved in this study included a level one mechanical engineering module on materials and manufacturing and a level three sport technology applications module. In both cases, the students have no previous experience in the use of FE modelling. As listed in **table 1**, FE modelling (using ABAQUS and ANSYS) was integrated with experimental work and theory to teach two typical materials engineering topics – extrusion and cycle design. The following illustrates the use of FEM in these two cases.

Use of FE in Teaching Materials Processing – Metal extrusion

Metal extrusion is a typical metal process, in which a billet of metal is reduced in cross section by forcing it through a die orifice under

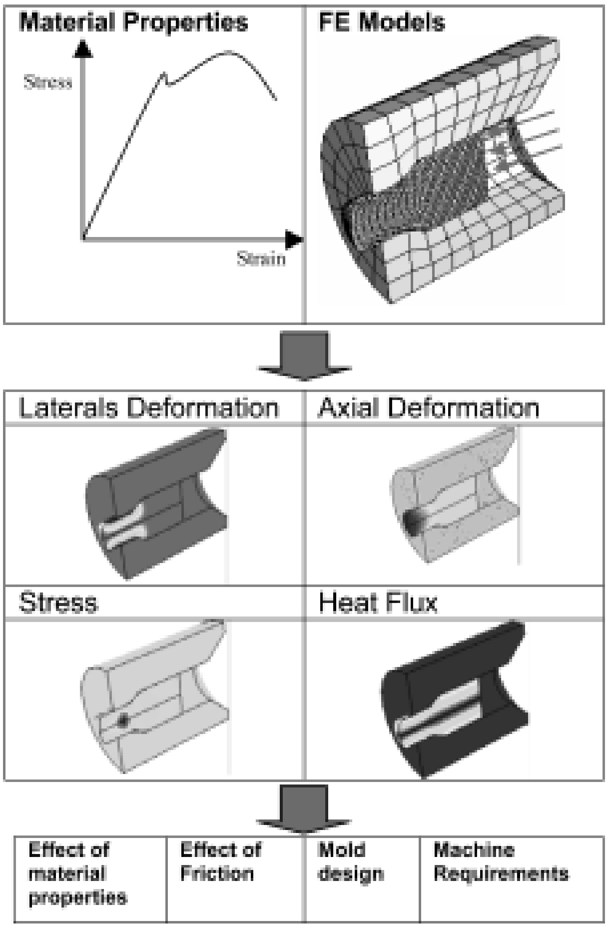


Figure 3: Typical example in using FE in teaching material processing (extrusion)

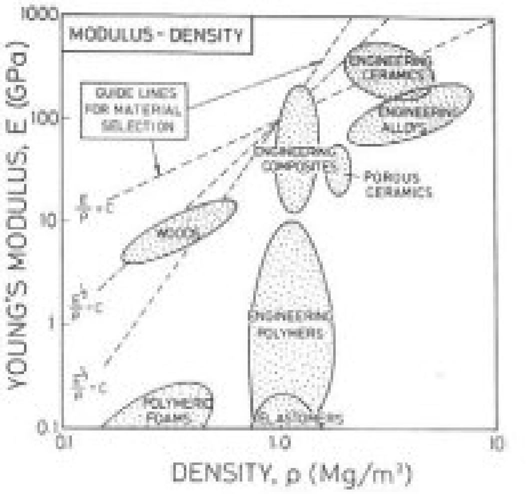
high pressure (**figure 3**). Typical parts produced by extrusion are trim parts used in automotive and construction applications, window frame members, railings and aircraft structural parts. The process (such as the force required, mould design, etc.) is directly affected by material parameters, (e.g. yielding, strain hardening) and other factors (e.g. friction between the billet and the wall, temperatures, etc.). These important relationships are difficult for the students to understand even though they can perform calculations based on empirical (or analytical) equations. The students also have difficulty in appreciating the uneven deformation of the materials during an extrusion process.

Figure 3 shows a typical approach in using FEM to link the teaching of material properties and the extrusion process. First, materials were tested in the lab including aluminium, copper and low carbon steel. The force-displacement data was processed to work out the required material properties (E, v, and strain hardening, etc.), which were used as input data in a pre-developed FE model. The simulated results obtained from different materials were directly compared, which can be clearly presented by combination of contour plots similar to those shown in the figure. This approach worked well as an effective way to explain the effect of the material properties on the extrusion process and the deformation of materials at different stages. Effects of other parameters (such as friction, operating temperatures, etc.) were also comparatively studied in the lectures. This methodology has effectively linked the material properties, die design, material behaviour (deformation, stress/strain) and machine requirements together. This has been well received by the students and showed clear improvement on their learning together with making the lectures more interactive. This approach can be transferred to the teaching of other manufacturing process, such as rolling, machining, forging etc. to help to improve the students' understanding of material behaviour in processing.

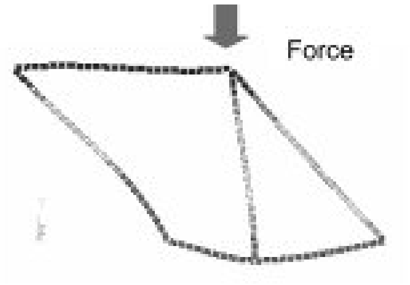
Use of FE in Teaching Materials Selection: Cycling Frame Design

Sport Technology Applications is a level three module in JMU which covers biomechanics and design concepts of sport equipment for a range of sports (golf, running shoes, tennis racket and cycling). In the teaching concerned with cycling, FE modelling was used in the lectures, tutorials and coursework with the aim linking biomechanics, materials selection and design.

FE models were used to demonstrate the deformation of a cycle frame made of different materials and cross sectional areas. The students were asked to suggest potential materials for different parts of the bicycle based on their understanding of cycling biomechanics. Their suggestions were then incorporated in the FE model to demonstrate the effectiveness of their suggestions. This has significantly increased their interest in the topic and has helped them to build up a network of knowledge on materials and design.



(a): An example materials selection chart used to select suitable candidate materials (Ashby[1])



(b): Typical FE result showing the deformation of the cycle frame

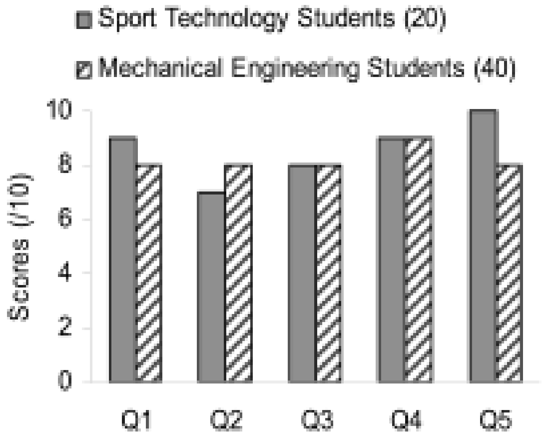
Figure 4: Use of FEM in materials selection in design

In tutorial sessions, students worked in pairs to build their own FE model of a cycle frame following a step by step guide. They then repeated the modelling procedures and changed the materials properties. This helped them to use FEM as a tool to learn about materials instead of putting all their effort in the modelling. Typical instructions included the necessary steps for building the model together with a detailed explanation of the material modelling aspects.

In the FE based coursework, the students were asked to design a cycle frame and select suitable materials to meet certain design limitation and loading criteria. Each student was assigned different design criteria and asked to use material selection charts (a typical example is shown in **figure 4a**) to choose potential materials based on mechanical calculations and compare the performance of these materials using FEM (**figure 4b**). A material selection chart allows the students to select materials based a combination of properties using a material performance index, such as stiffness over density (E/r) when designing light-weight structures. Details of the materials selection charts can be found in (Ashby M.F.,[7]). With FE modelling, the students can directly compare the materials against the design criterion. In the case of a cycle frame, this can be the maximum deflection under the bodyweight of the rider, etc. Some visualisation functions of FE (e.g. contour plots) can show the deformation mode (**figure 4b**), peak stresses, stress concentration points, bending moments, reaction forces, etc. This allows the students to evaluate the impact of materials selection on design. With the parametric function in FE, the material properties can be automatically changed over a predefined range and their performance compared. This can also help students to understand the impact of new materials on design. In these activities, the students had to link mechanical design with materials selection using FE modelling to make a sound choice of materials. The use of FEM extended the use of material selection chart and provided the students with a tool to directly assess the suitability of their material choice and quantitatively compare performance.

Student Survey Results

The impact of the project on the student learning was evaluated by questionnaires and peer review. **Figure 5** shows the survey results for students studying two different programs (20 sports technology students and 40 mechanical engineering students). Most of the students are strongly in favour of the approach. The sports technology module involved is a multidisciplinary program including engineering, biomechanics and sports science and the students have relatively limited experience on modelling and design. They strongly favour this approach to help their teaching in particular linking the knowledge from different disciplines.



Questions: Do you think this method:
Q1 Makes the lecture more informative
Q2 Keeps your concentration in the class
Q3 Make your learning more interesting
Q4 Helps you with linking Materials, Design and Manufacture
Q5 Is potentially beneficial to your future job/job hunting

Figure 5: Typical questions to assess the effects of the approach and scores for two learning groups

DISCUSSION

In general, the work showed that systematic use of FE could significantly improve materials teaching. The impact of the project on the student learning evaluated by questionnaires and peer review showed that the materials teaching with FEM is more: Interesting and informative. It not only provides students with very informative lecture materials and but also provides the students with a unique learning opportunity. With facilitation of the FE, the teaching was much more interactive due to the fact that the lecturer could use the FE models to demonstrate the answer in response to students' questions. This is an important factor for effective lecturing. Another significant benefit lies in the capability of FEM in linking materials, design and manufacture to provide the students with a network of knowledge rather than disjointed parts. For level one students, the lectures developed using FEM help them in developing the correct concept towards materials and design and manufacture. At higher level, the FEM based coursework provided the students with an opportunity to build up their knowledge network, which is an effective way of learning (Ramsden[8]). The FEM helped them to adapt to a deep learning approach and made it possible for them to try and assess new ideas. All these could potentially have long term effect on their learning ability in/after the university (Assiter[9]).

When teaching modules with students from mixed programs, there may be significant diversity of their knowledge and experience in modelling. Some students may tend to misunderstand the main aim of the course as modelling rather than materials. It is important to set clear course objectives and assessment criteria of the coursework to focus on materials teaching rather than pure modelling skills. The teaching materials should be aimed at students with no previous knowledge on FE modelling to avoid disadvantaging students with less previous experience. Models can be designed for a specific concept thus making the delivery much easier and focused. It is very easy to set individual tailored coursework without incurring high cost or marking load.

CONCLUSIONS

In the work presented here the use of FE simulation for materials teaching was studied using specially designed lectures and coursework in both materials engineering and sports technology modules. Results showed that the analysis and visualisation functions of FE made teaching more interesting and informative. Simulation based coursework resulted in a significant improvement in the learning behaviour of the students and encouraged deep learning and teamwork. FEM can be used as an effective tool to link materials, manufacture and design.

ACKNOWLEDGEMENT

The work is sponsored by the UK Centre for Materials Education and Faculty of Technology and Environment, Liverpool John Moores University. The authors are also grateful for colleagues involved in the peer review of the work.

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