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ACTIVE LEARNING IN MATERIALS SCIENCE AND ENGINEERING

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ABSTRACT

Active learning is not only a key element of CDIO syllabi, but is expected to increase student motivation, commitment and retention. The incorporation of active learning elements into a materials engineering programme is considered by means of three example modules. The implications of introducing these modules into a materials programme is discussed in terms of five Ts – their titles, testing, teamwork, timetabling and the totality of the student experience.

INTRODUCTION

In substantial parts of the world, notably the UK and USA but also elsewhere, there is a worrying lack of awareness of the discipline of Materials Science & Engineering (MS&E). This results not only in difficulties in recruiting the best students to the discipline, but subsequently in engaging them so that they extract the greatest possible benefit from their education. In this paper we explore attempts to motivate and retain students by exciting them about Materials Science, particularly by encouraging them to take a more active role in their own learning within the context of CDIO, and placing more of their learning activities closer to the practice of industrial materials scientists and engineers..

So far the majority of work in the CDIO initiative has been based around "traditional" engineering disciplines – mechanical, aeronautical, civil etc. We now consider how this approach can be applied to MS&E.

In Materials undergraduate programmes, laboratory experimental work traditionally occupies 10-20% of student time, increasing to perhaps 30-50% during a final year (or "capstone") project. In many countries (including the UK) this orthodoxy is being challenged from three directions: health and safety requirements impose limits to certain types of activity and demand greater supervision and hence staffing levels; the high cost of individual experimental work is increasingly being identified and downward pressure on costs have forced a reconsideration of its value to the student experience, and; the increasing availability of sophisticated IT offers opportunities for different types of "experimental" work and for new interactive learning experiences e.g.[1].

In this paper we address some ways of strengthening Active Learning in terms of five Ts: Titles of modules; Team projects; the Total experience; Testing understanding and the Tyranny of the timetable. Many active learning experiences can replace traditional "labs". We will use as examples three active learning modules currently running at the University of Liverpool. These are an introductory class entitled “What’s it made of?”, a first-year intensive exercise “The two-week creation” and a second year problem-based class in which an automobile door is re-designed following an evaluation of new materials and processes.

ACTIVE LEARNING MODULES

We will first describe each module then review the five Ts, and evaluate the extent to which each module meets CDIO objectives and how it is affected by the five Ts.

What’s it Made of? (WIMO)

All students registered for our Engineering degree programmes undertake a common first year set of eight modules. One half-module is reserved as an introduction to the student’s specific degree programme, while the other seven and a half are identical. WIMO is the first year module which is specific to Materials students taking a BEng or MEng degree such as Materials, Design & Manufacture and also to those taking non-accredited BSc programmes such as Design & Technology with Multimedia. Students in these latter groups may not have studied chemistry and some may have only very rudimentary mathematics. As an indicator of the level of prior knowledge, many students in recent years have entered this module without knowing the names of any of the elements – they may not know that copper is an element, nor that its symbol is Cu.

The intended learning outcomes of this module, as stated for the students in its module specification, are shown in the box.

WIMO; Intended Learning Outcomes

Knowledge and Understanding: On successful completion of the module, students should be able to demonstrate knowledge and understanding of:

- the range of natural and man-made materials available to the engineer and designer
- how materials can be classified based on materials science principles
- the range of properties which are potentially useful in each of the major materials classes
- how a designer might choose a material for a particular purpose.

Intellectual Abilities: On successful completion of the module, students should be able to demonstrate ability in applying knowledge of the above topics to:

- describing and explaining qualitative aspects of materials, their properties and approaches to classifying and selecting them
- classifying materials
- selecting materials for a particular purpose.

Practical Skills: On successful completion of the module, students should be able to show experience and enhancement of the following discipline-specific practical skills:

- using specialist materials computer databases.

General Transferable Skills: On successful completion of the module, students should be able to show experience and enhancement of the following key skills:

- IT skills
- oral presentation skills
- group-working skills
- problem-solving skills.

The vehicle through which these learning outcomes are delivered is the development, by teams of students, of a unique materials classification scheme. In teams of five or six, the students must select an industry sector and then devise a classification scheme meaningful to that sector. They are encouraged to consider a wide range of “industry sectors”, which in past years have included jewellery manufacture and the film industry as well as more obvious heavier industries such as building, aerospace or automobile. This brings into play a very wide range of material properties. The module is run entirely in a workshop format, with no formal lectures, but a couple of seminars by industrial materials designers. Most recently these were a materials technologist involved in the interiors for Bentley cars and a craft jeweller. The whole module involves twelve two-hour or 24 one-hour sessions – see below concerning timetabling. The teams brainstorm materials properties and have to research terminology and property value ranges. They make four presentations throughout the semester, worth a total of 30% of the marks for the module. The remaining 70% is assessed by a single exam which has a multiple-choice section to test vocabulary and an open section in which each student has to describe his/her scheme and then apply it to three "unknown" artefacts. This ensures that individuals have the opportunity to be assessed on their own work, independently of team performance.

This module has been successful in developing an understanding of the need for, and limitations of, materials design and selection. It also introduces students to a key piece of software – the Cambridge Engineering Selector (CES [2]). It has enabled students to appreciate the reason for the need to study many of the later modules in their programme. It has also thrown up many offbeat but inspirational ideas such as the significance of odour as a material property. The biggest problem with the module as it is currently structured is that many students find it difficult to appreciate that a classification scheme is value-free and that it is not a ranking scheme. Many of them cling tenaciously to the idea that if they classify according to stiffness then stiffer is necessarily better rather than just different. We need to work harder to get this point across, perhaps by arranging that the classification schemes have to be used at an earlier stage of the module. Formal feedback from the students indicates that they most appreciated the talks by practicing engineers and the opportunities to develop presentation skills. Team working was seen as very positive by a significant number of students, but an almost equal number disliked it and/or could not come to terms with the compromises, negotiations and organisation involved. Some students commented that listening to other students making presentations was a waste of time, even though the material presented by the students was not covered elsewhere in the module.

Materials Design

As part of the "materials design" activities undertaken in the second-year, all students undertake a major material and process selection exercise entitled "21st Century steel for Car Doors". The intended learning outcomes, detailed below, include very specific technical understanding, as well as more general transferable skills such as committee skills associated with industrial practice, and which are unfamiliar to students:

Materials Design (21st century Steels): Intended Learning Outcomes

Knowledge and Understanding: On successful completion of the module, students should be able to demonstrate knowledge and understanding of:

- Steel Types and Uses: Steel grades have a classification system. Contemporary design of car bodies(including doors) required development of interstitial free (IF) steels of which ultra-low-carbon (ULC) is one example. The meaning of ULC, IF and BH (bake hardenable) steels and when and why they are used. The difference between hot and cold rolled steels and the effect each process has on surface finish.
- Formability: The definition of 'formability', and the use of 'n' and 'r' in the context of sheet metal forming operations. How to use a forming limit diagram (FLD)
- Joining: Resistance spot welding (RSW) for car outer-body assembly, and that the key process parameters in RSW - weld current, weld time and weld force.
- Corrosion and Coatings: Coatings commonly applied to sheet steels and their function. The difference between 'sacrificial' and 'barrier' coatings, and how the thickness of a sacrificial coating is controlled in the galvanising process.
- Links between materials design factors: The implications of down-gauging for required yield strength, joining, forming and coating type, and that component optimisation requires a compromise between many factors including geometric design and material and process selection. That cost is a key factor in materials and process selection.

Intellectual Abilities: On successful completion of the module, students should be able to demonstrate ability in applying knowledge of the above topics to:

- Identify solutions to materials design problems, and/or identify the factors which are most important in providing a solution for a specific component.

Practical Skills: On successful completion of the module, students should be able to show experience and enhancement of the following discipline-specific practical skills:

- use of web resources in combination with other resources, to obtain useful technical information.

General Transferable Skills: On successful completion of the module, students should be able to show experience and enhancement of the following key skills:

- Group- and independent-working skills
- Committee skills
- Problem solving skills
- Time management skills
- Technical report writing skills
- Oral presentation skills

The “car door” exercise is delivered in a traditional PBL (problem based learning) environment [3, 4] 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” (full text in the box) links in directly with fictitious minutes of the Virtual Steel Company” Board and other resources provided, and has been carefully designed to require students to work through interactive ILSAP software [1], and other real technical information accessible only via the web. The “Car Door” part of the ILSAP website allows for the detailed study of steel selection and processing via interactive simulations, including mechanical testing, processing, and materials selection all using real experimental 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 available [5].

The Problem

You work in the research department of a major steel-maker. One of your key customers, the automotive sector, is facing increasing pressure from its consumers to improve safety, fuel efficiency and accessory specification. Weight reduction of certain car components is considered a key step in facilitating the improvements desired. This could be provided by steel's main competitor in the automotive marketplace – aluminium, which has already taken a proportion of the luxury automotive market and is looking to make inroads into high volume production models. You are a member of a committee, established within the steel-making company, tasked to ensure that steel can respond to this threat by identifying a suitable steel specification for use in a critical application – the car door outer panel. You will need to justify your decision to the company's Board, which will include marketing and research representatives.

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 have had of PBL, and staff notice it takes 4 or 5 weeks until students focus and identify the important issues, feedback from the students indicates an almost unanimous preference for PBL teaching. They also find the formal professional structured approach to meetings (agenda, minutes etc) helps them 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".

Two Week Creation

The third active module is the two week creation. This is a new module which will initially have three variants, not because of a need for diversity but because of the practical limitations of conducting 50 identical (and simultaneous) team exercises with the intended year cohort of 250 students. This module is a complete CDIO design and build exercise. Students, in teams of five, will design, manufacture and test a complete device. The three challenges, with their testable outcomes, are:

- A 50g aeroplane capable of out-of-sight control – assessed on endurance
- A water-powered rocket, with on-board altimeter – assessed on height with specified payload, and
- A cardboard bridge with a specified span – assessed on load/weight ratio

This module is under design, with its first run in academic year 2005/06. From the perspective of materials science each challenge will involve a significant element of materials selection and materials property evaluation. We anticipate being able to absorb into this exercise practice in using materials selection software and some aspects of materials testing

For all three modules it is clear that the ILOs are already written in terms of the CDIO syllabus and conformity with this aspect of CDIO is assured. However there are a number of aspects both pedagogical and practical of embedding modules such as these into an existing undergraduate programme. Several of these are discussed in the remainder of this paper.

DISCUSSION: THE FIVE Ts

T1 - Titles of modules: We know of no research evidence, but it seems intuitively reasonable that student attitudes to a module should be in some measure controlled by what the module is called. Despite the publication of module specifications, learning objectives and class topics, the title is in practice just about all the student has to go on in shaping her/his attitude to the module before it starts. The other significant factor is probably word of mouth, but this is unlikely to operate rapidly enough for first-year students. We therefore consider that the module title is of huge importance, and ought to give a clear idea of the content and purpose of the module. This is a tall order for a phrase of three or four words, but we can try. The modules described here are called "What's it made of?" (WIMO for short), "Materials Design" (we need to do more work on this, although the main exercise in the module, described here, is called more precisely "21st century steel for Car Doors") and the "Two week creation" (TWC). At the very least these are more usefully descriptive than MATS109, MATS213 and ENG101.

T2 - Team projects: Team work is central to CDIO, and to almost all work in engineering employment. We therefore introduce the experience of working in teams at an early stage in every undergraduate programme. The three modules described here all require that every student works in a team, usually of four or five people. Wherever possible this is a multi-disciplinary team but we have not yet been able to free up the resources to enable the formation of teams with a very wide range of student backgrounds (see Tyranny of the Timetable below). A key remaining issue is the extent to which we need to offer specific training in team working. Our current perception is that this is necessary, because although many students will have participated in team activities such as sport or (for UK students) the Duke of Edinburgh Award scheme, they seem to have drawn very few lasting lessons about effective behaviour in a team [6-8].

T3 – Total experience: In their own way, each of the three modules described here offers a total experience, spanning C, D, I and O. In the WIMO exercise the product is a "scheme" whose content is almost entirely intellectual but which is capable of being tested, as indeed it is during the module exam. The students have to conceive and devise their own individual scheme from the perspective of their own choice of industry sector. With a class size of almost 40 it is straightforward to avoid any duplication among the seven teams.
The car door exercise is slightly less open, in that the fundamentals of the task are pre-determined. However the choice of alternative steels for the door is wide and a comparison must be made with other potentially competing materials. As a materials selection exercise it spans at least D and I, although the O (carried out through on-line simulated tests) can only be virtual.

The TWC undoubtedly covers the whole CDIO spectrum, with the student teams responsible for the concept, the design, the manufacture and the testing of each device. There is no time, as yet, for feedback to inform a second design, although we are considering devising a second-year exercise which would take the simple designs a significant stage further with the benefit of the increased student skill and understanding available a year later.

T4 – Testing understanding: Assessment in each of these modules embraces several elements of the CDIO principles.

In WIMO 30% of the credit is awarded for four team presentations, using (consecutively) the overhead projector, PowerPoint and a poster. Training in each of these styles is given during the module workshops, with about one hour of class time available for each technique. The remaining 70% of credit results from an apparently-formal exam, but this contains a vocabulary/understanding test, a written description of the scheme which has been devised and a practical test of the usage of the scheme. The only significant problem which has been encountered in three years of running this scheme is the problem of re-sit opportunities. Our University regulations require that every student should have the opportunity to be re-examined in a failed module. However most failures result from poor attendance at the workshops which form the bulk of the module and/or failure to contribute to the work of the team. This means that, although the examination can be formally re-taken, the student is unable to improve his/her performance because the team-work aspect cannot be re-created in the interval (using 3 summer months) between the first exam and the re-sit exam. Nor can the student easily devise a completely new scheme on his/her own without the benefit of attending any workshops or interacting with a team. This leaves little real alternative (in the UK system) to re-sitting the whole year of the programme with full attendance – an expensive option!

In Materials Design the car door PBL exercise is assessed at three points, with the assessments comprising an individual test of technical understanding, a written group "executive report", a group oral presentation, and a peer assessment of individual contributions to group activities. Since there is no formal written examination there is in this case no re-sit opportunity.

For the TWC the assessment credit has been incorporated within the primary first-year "Design" module. The smaller element of the credit will be awarded for a team oral presentation after the first week of work, while a larger element will be awarded for a written "full report" to be submitted a few weeks after the end of the exercise.

T5 – Tyranny of the Timetable: In common with many UK engineering programmes our current student environment involves a substantial number of timetabled "contact hours" in which lectures, tutorials and laboratory classes are "delivered". Our students also share modules with students from other departments and programmes, and have the right to attend language modules at fixed times in the week. There is also a strong pressure to leave Wednesday afternoon free for sporting activity. This results in a timetable for a typical student with about 20-25 hours fixed, from a total of 36 available hours, with several modules immovable and 4 or 5 hour-long slots unusable. In 2004/5 it was not possible to fulfil a request for WIMO to be allocated a two-hour slot each week and it had perforce to run in two one-hour slots. This frustrated the ideal circumstances for a workshop-based active module! In subsequent negotiations with the actual students (38 of them) no alternative time could be found at which they could all gather. This "tyranny of the timetable" is the background against which innovative modules and methods must be introduced.

Similar problems beset the clearing of two weeks of the timetable for the TWC. In this case the problems relate to mandatory modules which are shared with students from other programmes – principally mathematics and electrical engineering. It is necessary either to tolerate a few classes interrupting a two-week period which is intended for intensive project work, or to persuade the directors of other programmes to accept the re-scheduling of classes (if this proves possible, which is at present unlikely).

It is instructive to consider the reasons for this tyranny. They relate to four key features of modern undergraduate education (in the UK anyway):

- Over-dependence on the "lecture";
- The drive for greater apparent "efficiency" resulting in increasing student/staff ratios and thus class sizes;

- Over-assessment, at least in the form of formal examinations;
- Reluctance of students to take ownership of their own learning.

It could be argued that at least three of these factors are in our own hands, and that the CDIO movement is addressing them.

CONCLUSIONS

CDIO for materials engineers is not appreciably different from that for other engineering disciplines. The four CDIO processes only differ from those relating to aero engineers or civil engineers in that the conceptual stage involves imaginative selection of materials possibilities while the D, I and O are of course carried out in the context of a manufactured artefact. Those materials science or engineering students whose programmes run alongside those of other disciplines such as mechanical engineering (and this is probably the majority) can contribute valuable input to the design and build process. At the same time they are exposed to the same CDIO elements of the syllabus. Have we been able to remove any conventional "laboratory" exercises because of the introduction of active learning? Yes, in the areas of materials selection, "reverse engineering" and mechanical testing. However there is still an important place for "conventional" laboratory experiments with students being introduced early on to the key practical skills required of graduates from their discipline. This can be done in less than half the time currently taken. For materials engineers, the important skill is how to use the standard tests available in industry to inform selection of both materials and processes for an engineering application. The ILSAB interactive simulations, for instance, give students of any engineering discipline anywhere in the world, "virtual" access to real mechanical testing processes applied to real materials in real engineering components. The important thing should then be not that they have successfully make a measurement (which is often all that comes out of many "conventional" practicals), but that students are given a context in which they have to do something useful with their information/measurements.

The most significant problems relate to implicit and explicit deviations from recently codified and needlessly uniform quality assurance procedures in the UK. Among these are the expected frequency of assessment, the rigidity of the timetable and potential effects on students' rights of re-sit. None of these is insurmountable.

The effect of these particular modules, together with other changes towards active learning implied by the CDIO standards, on student motivation, retention, and commitment are expected to be positive. We will be monitoring student results and behaviour as the cohort of students exposed to these new approaches moves towards graduation.

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