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Open Learning in Engineering Education

The Report of the EPC Working Group on Open Learning

FOREWORD

There is a great deal of evidence within universities of changes taking place which affect teaching methods. Undoubtedly, the future will require us to be even more imaginative both in the design and delivery of taught material. This present report addresses the topic of open learning. It offers a methodology which academic staff may use to evaluate the various teaching stratagems at their disposal and plan the most effective use of modern methods to suit their particular situation or requirements.

The recent announcement by the Secretary of State of the Review of Higher Education to be conducted by Sir Ron Dearing, with its invitation to make recommendations on how the shape, structure, size and funding of higher education should develop to meet the needs of the UK over the next 20 years, has given even greater relevance to this report. There will, no doubt, be calls for an increase in 'open', 'distance' and 'independent' learning, so this latest EPC Occasional Papers is timely.,

The EPC is grateful to the members of the Working Party, and in particular to its Chairman, Professor John Sparkes, for the time and effort which have been invested in the preparation of this publication.

Professor John Spence
Chairman of the Engineering Professors' Council

Open Learning in Engineering Education

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Summary

This report considers the various way in which engineering teaching might be made more 'open' as to: students, content, teaching methods, timing, access, location, assessment methods, etc; where 'open learning' is regarded as a relative term rather than an absolute one. That is, some courses are more 'open' than others.

The report offers a methodology for evaluating and prescribing teaching and study methods including independent learning methods. A distinction is drawn between different kinds of carefully-defined learning, namely: 'knowledge', 'skills', 'understanding' and 'know-how' in the cognitive domain and 'attitudes and values' in the affective domain, as in the Occasional Paper EPC 6 (*Developments in First Degree Courses in Engineering*). These concepts are distinguished in terms of their inherent characteristics as well as in terms of appropriate teaching methods. This Taxonomy of Learning is applied in some detail to different ways of using computer-based methods, video tapes and TV, problem-based learning, tutorials, lectures, laboratories, etc. with the aim of explicating how to make courses more effective as well as more 'open', whilst nevertheless preserving standards. The aim of the report, therefore is to help university teachers plan effective and more 'open', campus-based courses, mainly by including independent learning methods where possible.

The overall conclusions are:

- that it is important to ensure that all teaching methods - both face-to-face and independent learning methods - are used appropriately;
- that if properly used independent learning methods can enhance the effectiveness and openness of university courses.

The report includes:

(a) appendices on three case studies of the inclusion of independent learning methods in typical campus-based courses, and

(b) comments on alternative ways of analysing learning and teaching which serve to explain why we adopted the Taxonomy of Learning described in the report.

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Open Learning in Engineering Education

1. Introduction

This enquiry into open learning is timely for a number of reasons. Perhaps the most urgent is the Government's requirement that universities must accept increased numbers of students into higher education without a corresponding increase in resources. There is the hope that open learning methods might offer a way of ameliorating the worse effects of this continually deteriorating situation.

In addition however our analysis of the relationship between different kinds of open-learning methods and different kinds of learning is very relevant to the assessment activities of the Higher Education Funding Councils for England and Scotland currently being applied to the teaching activities of universities. It is also relevant to the Engineering Council's insistence in their report(1) on the importance of 'independent learning' as means of achieving continuing professional development throughout an engineering career, since open learning can make this possible without interrupting employment. In addition it has implications for the growing emphasis on 'competence' in vocational qualifications introduced by the Employment Department through the National Council for Vocational Qualifications(2,3).

More generally, however, as the era of mass education unfolds, and educational technology continues to grow at an ever increasing pace, there is an urgent need to appraise the educational effectiveness of these various developments. We have not, of course, been able to evaluate each existing open learning provision, since there is so much of it and we do not have the resources to undertake such a task. So we have concentrated our efforts on defining a methodology by means of which alternatives to face-to-face teaching can be evaluated in terms of the kinds of learning which they best support. In practice this mostly involves evaluating the use of independent learning methods in campus-based universities, because adding these methods to face-to-face methods enables teaching methods to be better matched to students' needs as regards level, pace, access, location, etc. Defining this methodology is the theme of Sections 3 and 4. Section 5 applies the methodology to a variety of independent learning methods, as well as to face-to-face teaching methods. Section 6 is concerned with the issues of implementing such methods. Sections 7 and 8 are concerned with conclusions to be drawn from the report and recommendations we feel able to make. We had intended to include a survey of available open learning material, but have not done so since the scale of the activity is vast and the scene is changing so rapidly. Mukesh Bhatt, one of the members of the Working Group, (See Appendix D), can provide, on request, up-to-date information on available open learning materials on particular themes.

Our methodology differs from a number of others that have been published(4). Appendix B briefly discusses these alternative approaches and provides a justification for our own approach.

2. The meaning of 'open learning' in the context of engineering education

A helpful approach to the study of 'open learning' is to regard it as a relative term rather than an absolute one(5). That is, some forms of education are more open or more closed than others and no form of it is wholly open. 'Wholly open' education would mean open to everyone, at any time, at any place, at no cost, with no prior preparation, and so on, which is quite unrealistic. It is also clear that open learning is not synonymous with 'independent learning' or 'distance learning' although it can be expected to make considerable use of them. That is, campus-based universities can be so organised as to be more 'open', as well as include the use of independent learning materials in their courses (such as computer-based methods) to increase 'openness'.

Most engineering degree courses are at present campus-based, with fixed terms or semesters, involving mostly face-to-face teaching in lectures, tutorials and laboratories, with students who have reached a prescribed level of prior education. In other words, engineering education is traditionally fairly 'closed' in character. One of our first tasks was to try to establish the kinds of openness which might be appropriate in engineering education (EE).

We based our approach to this task on a paper by Roger Lewis(6) entitled "What is Open Learning" in which openness is considered under various headings. The following table is based on a similar table in Lewis's paper.

The first column, comprising questions relating to the learning process, is essentially Lewis's first column. The second column describes traditional engineering courses, which we took as a 'closed' baseline to work

Table 1. An Open-Closed analysis

Basic question	Closed	Open	Max. openness in EE
Who?	Selected groups (e.g. 3 Cs at A level) aspiring engineers	Open to all	Very varied backgound (e.g. weak in maths).
Why?	Qualify for a specific degree	No constraints	To acquire good education with engineering bias plus a useful degree
What?	Choice of 3/4-year degree course (note 3) Courses fixed	Learner defines topics ("pick and mix")	Choice limited to coherent pattern of modules, and to fit degree title
How?	Limited choice of traditional methods	Learner chooses learning methods	Teaching methods matched to educational aims (note 1)
Where?	Campus based	Learner chooses	Campus plus home-based learning, or in industry, or in franchised colleges
When?	Fixed times for attendance	Start and finish any time	Fixed times plus self-study modules at any time plus open access to computing facilities including PCs
Assessment of progress?	Typically formal exam plus project plus some continuous assess^mt^.	Learner chooses assess^mt^ methods and timing	Assessment appropriate to educational aims (note 1)
What helps?	Tutors, libraries lecturers.	No constraints	Tutors, teachers, libraries, fellow students, colleagues at the workplace, CBM (note 2), various resources.
Goal?	One target destina^tn^: engineering	Many professions	Responsible employment of many kinds, especially in technology-related or numeracy-related fields

Notes.

1. Educational aims need to be specified in terms of subject matter, level and kinds of learning, as suggested in EPC 6[7]. Assessment methods need to be matched to these aims, as shown in EPC 5[8].

2. CBM (computer based methods) can refer here to a variety of computer-based methods such as computer conferencing, Internet, multi-media, CBT, CAL, etc.

3. In Scotland the courses are usually one year longer.

from. The third column indicates the ultimate in openness which still makes sense, but not necessarily in the context of EE. The fourth column contains our answers to the questions in the first column as they apply to possible future patterns of EE after they have become more open. Thus the main ways in which EE might become more 'open' are in:

- the variety of students that it accepts into its first or second year courses;
- the range of courses that it offers, either by allowing a wider range of module choices within an engineering degree, or by offering a number of prescribed degrees (e.g. engineering with German, engineering and management, ordinary degrees, honours degrees, etc.);
- the extent to which educational methods can be chosen by students to match their preferred learning *styles*. (e.g. didactic teaching, activity learning, self-paced distance learning, etc.);
- the variety of teaching methods available to match to students' learning *goals*, whether these goals are chosen by the students or by the engineering department;
- the extent to which elements of courses can start at any time. (e.g. by the inclusion of self-paced independent learning modules in the degree programme, in such topics as languages, management, mathematics, etc.);
- the use of assessment methods which are matched to educational aims (e.g. by the inclusion of a wider range of continuous assessment methods, including computer-based assessments, in addition to formal exams and projects);
- the provision of a wider range of support for students (e.g. from computer-based methods to the use of peer tutoring);
- preparing students for a wider range of employment opportunities of all kinds, including finance, marketing, management, schoolteaching, etc. (i.e. not only those specifically related to technology).

3. Different kinds of learning

A key element in the 'opening' of university courses is the addition of independent learning methods. But these methods are less flexible and adaptable than face-to-face teaching, so more care needs to be taken in the design of such courses and teaching methods.

If we regard good teaching as the business of matching educational courses and methods to specified learning goals, teaching is much more than just classroom teaching or lecturing; it includes many techniques and methods. In order to match these methods to goals it is necessary to distinguish between different kinds of learning. The EPC has hitherto found it helpful to distinguish between 'knowledge', 'skills', 'understanding' and 'know-how' in the cognitive domain, and between 'values' and 'attitudes' in the affective domain. The skill of 'integrative thinking' is particularly important in engineering. A further key factor is 'motivation', for if students do not want to learn, for whatever reason, learning is unlikely to occur. This is discussed later.

Since these educational terms are used very loosely in everyday discourse, as well as in much educational literature, we explain in the following paragraphs the meanings we attach to these terms in this report. Further explications can be found in EPC 6[7]. Accompanying each definition is an indication of the teaching methods which are likely to be most effective at helping students achieve their chosen learning goals.

<u>*The cognitive domain of learning*</u>

Knowledge.

Knowledge is defined as information that has been memorised and can be recalled in answer to a question. (e.g. facts, terms, definitions, methods, rules, principles, incidents, events, the location of further information, etc). Information only becomes knowledge when people have remembered it and can recall it. All knowledge is, of course, underpinned by some degree of understanding, the deeper the understanding the wider the range of knowledge it is possible to embrace. With appropriate understanding and motivation, knowledge can be acquired very rapidly. In this it is quite unlike any other form of learning.

Teaching knowledge involves presenting the information, or ensuring that it is available (e.g. for 'discovery'), in the most appropriate and motivating form.

Skills.

A skill is best defined as "a complex sequence of actions which has become so routinized through practice and experience that it is performed almost automatically"[9]. Examples include speaking, writing, analysing, using a computer, touch-typing, designing, etc. Although some skills are called 'manual' and some are called 'intellectual', all are 'mental' in the sense that the learning occurs in the brain. For assessment purposes, it is worth distinguishing between 'measurable' skills - for which there are clear performance criteria - and 'complex' skills for which judgment is needed. Measurable skills include spelling, typing, programming, doing simple sums and many practical skills. Complex skills, which include designing, communication & interpersonal skills, decision making, etc., usually also involve integrative skills as well as the application of other kinds of learning.

Skills are taught by instruction and demonstration. They are learnt through practice, with error-correction when needed.

Understanding.

Because understanding can mean different things in different contexts it is usually necessary to define it in relation to a particular field of study, though it seems that the teaching and learning methods to assist understanding are much the same whatever the details of the definition.

Understanding in science and technology is best defined as 'the capacity to use explanatory concepts creatively in problem solving'. It is needed for tackling *new* problems responsibly (i.e. not simply by trial-and-error). Examples include explaining new phenomena and processes, designing new artefacts and systems, correcting unfamiliar errors and faults, asking searching questions, engaging in rational argument and discussion, and so on. Acquiring understanding consists of two parts:

(a) becoming familiar with the relevant concepts (e.g. feedback, energy, productivity, etc.) upon which understanding depends;

(b) being able to apply them to tasks such as those listed above.

Teaching understanding involves creating a 'rich learning environment', in which students can express their grasp of the key concepts as well as have them explained, and apply their understanding in practical activities - from problem-solving in laboratories to arguments and discussions with colleagues. Nowadays educationalists place great emphasis on 'active learning', to ensure that students do not merely absorb information. In practice 'passive' methods of learning, like reading a book or attending a lecture, can teach effectively if students already have 'active minds' (i.e. they adopt the 'deep approach', see Section 4). 'Active learning', such as practical problem-solving, often encourages the 'deep approach' but for those already wanting to understand it can be unnecessarily time-consuming.

Know-how.

Know-how also provides a problem-solving capability, but one that is acquired through experience (e.g. apprenticeship) and problem-based learning rather than through becoming familiar with the explanatory concepts and their application, which understanding involves. Thus solutions to new problems based on know-how are extrapolations from experience of previously successful activities (which may not however be understood), rather than on applications of theory. Medical training has to emphasise know-how rather than understanding because much of the human body is not well understood. In practice it is usual to teach some understanding, if only to help people make sense of their 'know-how', but it is not a necessary part of it, (see reference to 'construct-ivism' in Appendix B)

Know-how is a valuable basis for innovation *within* current practice, but understanding is needed for responsible innovation *beyond* current practice. Inventions, such as junction transistors, lasers, holograms, genetic engineering and atomic bombs could not have been based on know-how since they were beyond current practice and could not have been arrived at by trial-and-error.

The skill of Integrative thinking.

This skill has been singled out because of its particular importance in engineering design. Integrative thinking is the process by means of which - in ways which are not well understood - people are able to bring all their different kinds of learning, in both the cognitive and affective domains, to bear on problem-solving. It seems to be a natural human process when everyday concepts are involved, since life presents a continual sequence of complex problems, but integrative thinking needs to be practised when the specialised concepts of science and engineering are being applied, if simplistic solutions are to be avoided.

The affective domain of learning

The elements of the affective domain are well enough defined in dictionaries. (But see Bloom's taxonomy of the affective domain(10) in which, as with his book on the cognitive domain, he concentrates on 'objectives' rather than 'kinds of learning'.)

Motivation.

Motivation can be defined as "the internal process that arouses, sustains and regulates human and animal behaviour"(11). Motivation is discussed in some detail in Section 6

Attitudes and values.

Attitude can be defined as "the way a person views something or behaves towards it, often in an evaluative way"(11). It includes many personal qualities such as diligence, obstinacy, friendliness, etc.

Value can be defined as "worth, merit, or importance"(11). Values include moral values, social values as well as aesthetic values.

To develop attitudes and values, the key factors seem to be: (a) the example of others, especially of parents, teachers and peers, (b) experiential learning; (c) project activities which have significant social or aesthetic or moral implications; (c) the media, especially television.

Specifying different kinds of courses

If students' goals are expressed in terms of the above kinds of learning, as well as in terms of the traditional parameters of 'content' and 'level', and if both students and teachers are able to perceive these differences and act on them, both teaching effectiveness and motivation can be improved(12). For example, just knowing the difference between 'memorising a fact' and 'grasping a concept' can improve student performance significantly.

These differences between different kinds of learning can also be used to distinguish between different kinds of courses, and so ensure a better match between course descriptions and students' needs. For example,

- 'up-dating courses' can be defined as being mainly concerned with new 'knowledge' (the underpinning 'understanding' being taken for granted);
- 'training courses' can be thought of as mostly concerned with developing 'skills' or 'know-how';
- 'degree courses' are concerned with developing all kinds of learning but in varying proportions. Arts degrees emphasise values; science degrees emphasise understanding and medical degrees emphasise know-how. It is suggested in EPC 6 that in engineering, two kinds of degrees are needed: one which emphasises 'understanding' and one which emphasises 'know-how'. This difference has great practical importance in view of the differences between appropriate teaching methods.

A matter of some concern is the recent emergence(3) of the concept of 'competence' and its endorsement by the Engineering Council(1) as an important learning goal in the specification of vocational qualifications. It is not here regarded as a distinct kind of learning since it can be described as a mixture of specialist skills, knowledge and know-how, with limited understanding. A key clause in the NCVQ's paper, *Competence and Assessment* (page 38)(3) is "Questions to assess [knowledge and understanding] should not require students to use their knowledge and understanding in ways which are more complex than those necessary for the achievement of the standards." This rules out the broader and deeper understanding needed for responsible innovation *beyond* current practice. Very little understanding is needed to underpin most forms of competence. As Ronald Barnett(13) puts it "For understanding read openness; for competence read closure".

4. Students' preferred learning styles

Research has shown(14) that students can differ in a number of ways as regards their preferred learning styles, especially when they are acquiring 'knowledge' and 'understanding', so good teaching should take these differences into account. With 'skills' and 'know-how' the learning activities needed are largely determined by what has to be learned, rather than by student preferences of learning style. But especially when they are learning 'understanding', students can differ significantly. For example:

- some students are 'holist' learners and prefer to take an overview of a subject before they fill in the gaps in their own way; whilst others are 'serialist' learners and like to follow a logical development of a subject(15). Books are naturally serialist in character, so their appeal to holist learners can be improved by adding summaries, signposts, explanatory figure captions, repeated explanations of difficult concepts, etc. Projects, on the other hand, are naturally holist in character, so serialist students may need help with them.
- some students are 'visualisers' whose conceptual development and knowledge are helped by the inclusion of diagrams, pictures, TV, etc.; some students are 'verbalisers' and find reading, listening or discussing most helpful; whilst others are 'doers' and prefer to be active during their learning (e.g. learning by discovery).
- some students naturally adopt a 'deep approach' to learning (i.e. the intention to understand and to challenge statements and compare them with experience), whilst others naturally adopt a 'surface approach' (the intention to memorise information and practise skills without question)(16). However the approach that individual students adopt varies with the subject and with motivation and can often

be altered (in either direction) by different teaching and assessment styles. The 'deep approach' - which is alternatively expressed as having an 'active mind' or the willingness to 'reflect' on experience - is essential if students' understanding is to be developed, and is in any case desirable for other kinds of learning, so methods of encouraging it may be needed.

An important consequence of the differences between students' preferred learning styles is that feedback from students regarding the success of a particular course or teacher is likely to say as much about the students themselves as about the courses or teachers being evaluated; so more searching questionnaires and more detailed analyses of feedback are needed before student feedback can be used responsibly.

A further important step towards increased openness is helping students to become aware of their own preferred learning styles, as well as of different kinds of learning, so that they can look for appropriate teaching methods and styles and so take better control of their own learning.

Much can be done in the design of learning materials and teaching methods to 'open' them, or make them more accessible to a wider variety of student learning styles. Enabling students to study in their preferred learning styles can be expected to improve their learning as well as improve their motivation to learn.

5. Alternatives to face-to-face teaching and their capabilities

Introduction

The term 'teaching' here refers to any deliberate action by a teacher to advance students' learning, so it is a much broader concept than simply instruction. It ranges from lecturing and writing teaching texts and programs to problem-based learning, projects and arranging apprenticeships.

This section lists a number of teaching methods which enable students to learn independently of their teachers. These are usually called 'independent learning methods' - 'distance teaching methods' if used in off-campus courses - because they refer to methods in which students meet their teachers only occasionally at most. These days they are of interest to campus-based universities because they offer a possible means of coping with larger student numbers, of providing continuing professional development (CPD) and of exercising and encouraging the skills of independent learning, all of which can contribute to 'openness'.

The list is more complex than a catalogue of various forms of educational technology, since each teaching technique can be used in different ways according to the kinds of learning expected of the students. Thus the list briefly describes different ways of using each particular technique and indicates the kind(s) of learning, as defined in the Taxonomy of Learning given in Section 3, to which they are best suited.

The list can be used as a means of matching the teaching provided (a) to the kinds of learning expected of students; (b) to the preferred learning styles of the students; (c) to the circumstances and facilities available to the students. It is assumed that students will be mostly campus-based, rather than remote as at the Open University, so that the methods listed will normally be supplementary or in place of some of the face-to-face teaching already being provided. Thus once the 'kinds of learning' that a particular course is intended to facilitate is settled, it is possible to use the Taxonomy to design an effective mix of teaching methods for that course.

This analysis of the learning processes is briefly compared with other methods in Appendix B. Fuller descriptions of these different kinds of analyses are to be found in the publications therein referred to.

First let us note that *lecturing* and *tutoring* are the face-to-face teaching methods which are mainly responsible for the 'closed' nature of university courses, both as regards physical and intellectual access and as regards timing. Even laboratory work is less dependent on teacher-student contact than these two teaching methods. Lectures can however contribute to increased openness if they are better designed to meet students needs, are fewer in number as suggested in EPC 6, and are timed to be more accessible, for example, to people in part-time work. Tutorials similarly can be matched to learning needs by structuring them appropriately. Remedial tuition, for example, where the tutor deals with students' particular difficulties and mistakes, is good for teaching knowledge and skills. But for the development of understanding 'group working' is preferable, in which the tutor is more a facilitator and creates immediate common challenges for students to deal with and explain to each other, and so sort out their own misunderstandings.

Printed texts and books

Few textbooks are designed with teaching particularly in mind, although, of course, they are intended to be sources of information and often set questions for students to answer. Printed *teaching* texts and books can be structured differently according to the kinds of learning they are designed to support.

Text type A. Presents information clearly, using visuals where helpful; is well indexed with good summaries, etc. (Many descriptive books are of this kind.) It is mainly *for teaching knowledge.*

Text B. Gives instructions on particular (usually intellectual) skills, gives illustrative examples, and sets plenty of exercises; *for teaching knowledge and skills.*

Text C. Explains theories and defines new concepts; presents illustrations of their application both in idealised contexts and in realistic case studies; sets problem-solving exercises to be solved using these and other concepts. This kind of text is *designed to teach understanding*, and will do so if students adopt a 'deep approach', but it can all too easily be studied in a 'surface' manner so that the information is merely memorised rather than understood.

Text D. Can be any of the above, but with a CD or audio or video cassette or practical kit added. These additions are unlikely to change significantly the kinds of learning that the package can deal with effectively, but it should increase the range of students that it suits.

<u>Problem-based learning</u>

Problem-based learning, on-the-job training, or simply work-based experience, are natural forms of learning and are good *for teaching specialist knowledge* and *for developing know-how.* Problem-based learning is not so effective for the development of skills, since time-to-practise is not usually part of the required activities. It only develops understanding if (a) the problems set require the application of the new underlying concepts being taught and (b) if the students' conceptual development is supported by other methods.

<u>Correspondence Tuition</u>

This is already a component of most face-to-face teaching. Calculations can be checked (and marked) *for the development of mathematical and modelling skills.* Students' written assignments can be commented upon, *to improve communication skills and develop understanding.* This is a key part of 'conversational learning' which is one important way of improving understanding (see Appendix B).

<u>The use of computers</u>

Personal computers, especially when connected to a network, can be used for learning in many ways, and new ways are being devised daily. The following are some types of educational uses to which computers can be put. (See the publications under Reference 4 for further examples of these uses.)

General tools, for word-processing, spread-sheeting, graphical analyses, etc, *for developing skills*, such as writing, accounting, mathematics, etc.

Computer-based drill and practice exercises (D&P). The computer must be capable of responding to students' outputs, which rules out natural language student responses. Multiple-choice testing is often used. The range of subjects for which direct responses are possible includes basic mathematics; simple aspects of languages such as spelling and transliteration; many simulated practical skills. *For developing measurable skills.*

Computer-aided instruction (CAI), comprising instruction and access to information, plus multiple-choice questioning (i.e. questions with right or wrong answers). *For teaching mainly knowledge.*

Computer-based training (CBT), comprising instruction, demonstration and testing. (e.g. D&P plus prior instruction and demonstration). *For teaching skills.*

(Intelligent) tutoring systems (ITS) comprise CAI plus the ability to respond constructively to students' multiple-choice selections. For example when students make a particular mistake they are provided with (hopefully) *appropriate* remedial instruction. However, the diagnosis of the causes of mistakes is fraught with difficulties so it is easy to expect too much of ITS. On a good day, ITS *can help to remove misunderstandings and improve skills.*

Resource-based learning (RBL). Computers and computer networks can give access to vast amounts of information (e.g. Internet, including Search Engines and World Wide Web). *Supports projects plus the learning of knowledge and know-how.*

Simulation A; in which students can practise *skills* without the dangers and expense of failure typical of real situations (e.g. flight simulators).

Simulation B; in which the performance of designs or problem-solutions can be tested by the simulation software. *For teaching design skills.* By penalising the use of too many simulation runs, students can be discouraged from proceeding by trial-and-error and encouraged to think or reflect, and therefore to *develop their understanding.*

Simulation C; in which the simulation software represents the properties and performance characteristics of some aspects of reality (e.g. economics, materials, management) which can then be explored by observing the system's responses to various inputs and thereby, discovering or creating interconnections. *Develops only know-how and knowledge unless accompanied by conceptual-development activities.*

Simulation D (Microworlds); in which (in science) the consequences of the laws of science can be explored in simulated form by observing the system's response to different inputs. In some realisations these laws can also be modified (e.g. an inverse *square* law can be modified to an inverse *cube* law) and the consequences explored. *For developing understanding.*

Multimedia, (e.g. hypermedia) can combine *Simulations B and C* as well as *CAI* and *RBL*. It can therefore help with several kinds of learning in the cognitive domain. Can replace actual experiments with simulated ones. However, too much faith in simulated experiments can be misplaced. Perhaps simulations with simulated errors would be beneficial. *Very expensive but usually motivating if done well.*

Expert systems (e.g. in medicine and trouble-shooting in engineering). These encapsulate the know-how of experts, and can be explored or used by students as a guide to practice. *For developing know-how* (i.e. expertise) more rapidly than by actual practical experience.

Computer-mediated communication (CMC):

CMC is especially useful for the conduct of computer conferencing and remote tutorials.

CMC A. Remedial tutorials at a distance. Students state their difficulties and the tutor provides remedial teaching and error correction. *For teaching knowledge and intellectual skills. Can help with understanding.*

CMC B. Group working at a distance on specified problems. Students collaborate in problem-solving activities, placing questions and possible answers and explanations on the 'bulletin board', to be answered and commented on, mainly by fellow students. If the problems demand the application of previously explained scientific or technological concepts this (like 'group working' in face-to-face tutorials) can be a key activity in *the development of understanding.*

CMC C. "Answer Gardens and Answer Webs" in which students questions and experts' answers are stored on a computer or on a web and made available from one year to the next.

CMC D. "Stadium", being developed by the OU, in which students, world-wide, can log on to hear and see a speaker live, and give instant feedback, ask questions and receive answers. *Provides all the features of lecturing without the closure of having to attend at a fixed location.*

The use of television and video tapes

Note that 'concepts' cannot be seen or photographed, so visual communication must always play a supporting role where conceptual development and the teaching of understanding are the aims. Most concepts in engineering have to be explicated in words.

Video A. Showing experts in action (e.g. counsellors or experimenters) *for the instruction and demonstration of skills* - but not for practising them.

Video B. Showing events and phenomena; *for the teaching of mainly visual knowledge* (e.g. natural history).

Video C. Showing phenomena which require the use of explanatory concepts for their explication. Can *support the teaching of understanding* provided the verbal explanations are allowed to dominate (e.g. in electromagnetism, 'magnetic flux' cannot be shown, it must be explained possibly with the help of diagrams).

Video D. Showing animations of abstract ideas (e.g. mathematical functions) *to support the development of mathematical understanding.*

Video E. Showing recorded instructional lectures for use as inputs to remedial tutorials (one form of Tutored Video Instruction (TVI) see Video F). *For developing knowledge and know-how* (e.g. for industrial training).

Video F. Showing recorded explanatory lectures for use as inputs to 'group working' tutorials in another form of TVI. *For teaching understanding* (e.g. semi-conductor science for industry at Stanford University[(17)]).

Video G. Showing dramatisations of important issues; *for stimulating interest, enthusiasm and motivation.* Much public service broadcasting takes this form (e.g. environmental issues or "The Chips are down", a video tape about the importance of integrated circuits which modified Government policy!).

Audio-vision

This is an audio recording accompanied by printed pictures, diagrams, tables of data, etc., to which references are made in the audio recording. (For explanatory purposes the balance between words and visuals is better than in Video C. It is also much cheaper.)

Audio-vision A. Presents tables, drawings, diagrams, etc., together with instructions as to how to use them; *for teaching intellectual skills.*

Audio-vision B. Presents explanations with supporting visuals for the purpose of *helping to develop understanding.*

Telephone communication

It has been shown by the University of Wisconsin-Extension at Madison, USA, that telephones and telephone conferencing can be very effective as a means of teaching-at-a-distance, especially for updating and awareness courses. (Ref 5. & Case study 1)

Dial access; by dialling specific telephone numbers, students can listen to recordings of helpful information and advice. Heavily used in the State of Wisconsin by medical doctors and students. *For extending knowledge.*

Telephone teaching; students in remote centres (plus a few in their homes) can be in communication with a tutor using loudspeaking telephones and press-to-speak microphones (sometimes plus a slow-scan video link). *For extending know-how and knowledge* (e.g. for updating nurses after a break for child-bearing).

Projects.

Projects are a natural form of 'open' learning since they are mainly self-directed with only occasional contact with teachers. There are many kinds of projects. Some only require access to, and the organisation of, information; some demand planning and practical skills; some call for innovation (and understanding) and some develop know-how. If well designed, *their main educational gains are in developing 'integrative thinking' and 'communication skills' in the cognitive domain and 'motivation' and 'personal qualities' in the affective domain.*

Evidently, if learning goals are expressed in terms of more than one element of the Taxonomy of Learning, it is possible to combine teaching methods to achieve these goals. Also different mixes of methods can be designed to achieve a specific set of goals.

6. Implementation issues

There seem to be three main issues associated with introducing independent learning methods.

Staff Attitudes

There is a natural reluctance on the part of most university teachers to replace, or even augment, lectures, tutorials and practical activities as their main teaching methods. One reason is that they are not sure that the considerable up-front effort needed to add independent learning methods to their well-tried face-to-face methods is going to be worthwhile. Even if these alternative methods are bought-in, rather than prepared in-house, a good deal of planning and organising is needed in order to reap the later benefits they might provide in terms of reduced teaching load and greater effectiveness without loss of standards. Also lecturers prefer teaching and real contact with students to late-night marking (see Case Study 1). Change and innovation are not inherently beneficial, so they need to be evaluated before they are introduced.

There are three main ways of achieving successful innovation, in education as in engineering:

(a) by trial-and-error, (i.e. innovation followed by evaluation). This is time consuming and wasteful and the error part of the process can damage people for life. (It hardly seems right to try out new educational ideas on people when it is an offence to experiment on them with dangerous drugs and technological artefacts.)

(b) by using 'know-how', and relying on people's experience and best practice, which is appropriate if only well-tried methods are involved; or

(c) by 'understanding' the problem and the processes involved and designing courses on the basis of an analysis of what is needed. This is essential for responsible innovation for the achievement of new educational goals.

The aim of this report is to develop a methodology by which teachers can evaluate new methods *before* they are implemented and so turn trial-and-error into trial-and-success or 'right-first-time'. (It can also be used to evaluate existing methods.)

Student motivation

Independent learning in engineering is problematic mainly because the conceptual development that science and technology demand is difficult and even uncomfortable. The concepts involved are very different from, and often conflict with, common sense concepts(18) (e.g. suitcases do not get heavier the longer you carry them, and it is very difficult to accept that light can be both wavelike and corpuscular at the same time!). So special attention may have to be paid to sustaining motivation whilst learning new ideas. In addition, learning them independently, when face-to-face teaching is expected, usually requires the support of a rich learning environment (see Case Study 3).

The main sources of motivation are: (a) interest in the subject; (b) the belief that the rewards of success are worth the hard work, which is strongly influenced by external factors such as the employment situation, and (c) the realisation by students that they are making good progress towards their intended learning goals (rather than towards apparently arbitrary goals set by the teachers). Interest can often be stimulated by 'active learning', though this on its own does not teach understanding without additional conceptual development. A key factor in achieving good progress is knowing how to learn and seeing that the teaching methods available are appropriate. This involves ensuring, as already indicated, that students can distinguish between different kinds of learning, can specify their learning goals in terms of them and can study in appropriate ways[12]. It also involves ensuring that teachers can make these distinctions too and act on them in both their teaching methods and assessment methods (see EPC 5 [8]).

In addition, various devices, such as giving students exemption from exams if they perform well during continuous assessment, and self-assessment and peer-assessment can also create a motivating climate[19]. But maintaining interest in the subject must remain at the top of the list, which is the function of good lecturing, challenging practical activities including tutorials and the provision of good facilities.

Quality and Costs

The cost of creating independent learning materials is difficult to justify unless large numbers of students study each course. Hitherto most such courses, even in the Open University where student numbers on many courses run to four figures, rely on Government support to make them viable.

A useful measure of the cost to an institution of preparing independent learning materials is the man-hours required to produce one hour's worth of student's work. Face-to-face lecturing is one of the least costly forms of teaching - though it does not always teach very well. It takes perhaps 2 hours for an experienced lecturer to prepare and deliver a one-hour lecture. If this provides each student with 2 hour's study, including attending the lecture, and there are 100 students attending, the cost is 0.01 man-hour's teacher-time per student-hour of study.

By contrast, the corresponding times required to prepare 1 student-hour's worth of independent-learning material can vary from a minimum of about 5 man-hours for Video F and Audio-vision, to over 20 man-hours for a well-structured teaching text and more than 100 man-hours for multimedia productions - because so many people are involved. So large student numbers are needed for them to be as cheap as lecturing. If lecturing were to be made more effective, in the sense that it were to become better matched to the intended learning goals, its cost-effectiveness would be difficult to challenge. Its main disadvantage is the various kinds of 'closure' it tends to enforce. (See Case study 3 in Appendix A, where 50 man-hours per student-hour of study has been achieved.)

7. Conclusions.

7.1. Campus-based courses in universities can be made more 'open' as regards: the timing and duration of studies, the use of different preferred learning styles, access by students with non-standard prior learning experiences, the frequency of attendance on courses, access by students to data and information, etc. A key aspect of increasing 'openness' of such courses is the use of independent learning methods in addition to face-to-face methods.

7.2. However, independent learning methods are less flexible than face-to-face ones, so greater care needs to be taken to match the methods used to the specified learning goals. These goals must be clearly stated at the outset before time and effort is invested in creating alternatives to face-to-face teaching.

7.3. Specifications of learning goals need to refer not only to the 'subject matter' and the 'level' but also to the 'kinds of learning' expected of students. The proposed Taxonomy of Learning, which distinguishes between 'knowledge', 'skills', 'know-how', 'understanding' and 'attitudes and values' (all carefully defined) makes it possible to map teaching methods onto learning goals without too much difficulty.

7.4. Methods can be matched to kinds of learning as follows:

- To teach 'knowledge', information needs to be presented, or made available, in the most appropriate ways. Books, data bases, video-tapes, audio tapes, Internet, experimental kits, etc. can be used to convey accessible information. Multiple-choice testing is adequate for the assessment of 'knowledge'.
- For the instruction and demonstration of skills, video-tapes are often better even than one-to-one, face-to-face methods, even of intellectual skills, because of the hold, slow-motion and replay facilities they offer and because the performance of world experts can be demonstrated. Also, because it is easier to *know* how to do something and *recognise* good and poor performance than to be able *to do it* well oneself, self-correction during practice is often possible. With measurable skills CBT is effective without extra support. To develop written communication skills, word-processing is helpful; to develop financial and budgeting skills, spread-sheeting is helpful.
- To teach 'understanding' (in science and engineering) a rich learning environment is normally needed (see EPC 6). To be effective using independent learning methods it seems that CAL plus 'an intensely supportive environment' is needed (see Case study 3). Whether or not, during the brief period of a degree course, a 'rich' enough learning environment can be created without some face-to-face methods, has yet to be established.

- To develop 'know-how', experiential learning and problem-based learning are needed. These can be achieved to some extent independently through simulation and the use of 'expert systems'. (Note that problem-based learning does not develop understanding - as here defined - unless prior conceptual development has been introduced.)
- To develop 'complex skills' and 'attitudes' and 'values', projects of various kinds, which are naturally fairly independent of face-to-face contact with teachers, can be effective, though guidance and supervision may be needed.

Degree courses usually involve the development of all kinds of learning to some extent. The proportions vary, so different mixes of methods are needed. The two kinds of degrees for engineers suggested in EPC 6, one of which emphasises 'understanding' whilst the other emphasises 'know-how', would have significantly different structures.

7.5. Student motivation to learn is of course vital for any kind of learning, but is particularly important (a) with the difficult kinds of learning involved in the conceptual development in science and technology, and (b) when unfamiliar ways of learning, such as methods of independent learning, are involved. An essential element is to ensure that students adopt a 'deep approach' to learning, for which periods of 'active learning' may be needed. It is also as important that students learn how to match their learning methods to their learning goals, and so take control of their own learning, as it is for the teaching methods to be appropriately designed.

7.6. The cost of producing independent learning methods, measured in terms of man-hours to produce one-hour's worth of student study, is far greater than lecturing, or even than tutoring, but these methods can achieve cost-effectiveness with some kinds of learning if they are well-designed and teach large student numbers.

8. Recommendations:

1. The openness of university courses can be increased, without loss of standards, using independent learning methods and deploying face-to-face methods more effectively, provided these methods are well matched to the kinds of learning required and to the kinds of students involved, as indicated in Section 7.4. However such methods can only be recommended after favourable analyses of cost and effectiveness, using the methodologies in the report, have been carried out.

2. Innovative teaching methods, followed by evaluation, without prior analysis, is not recommended.

3. Evaluation of methods (and teachers), in terms of student feedback, needs to take into account students' differing preferred learning styles.

4. Staff development on how to achieve courses which are well matched to both goals and students is strongly recommended, since no methods, not even 'active learning', are appropriate in all circumstances.

5. Similarly students need to be taught how to achieve the different kinds of learning they want - or are expected of them - whether they are involved in face-to-face teaching or independent learning.

6. New teaching methods need to be introduced into a department as part of a proper (e.g. 5-year) teaching and learning plan. Indeed a co-ordinated, possibly national, approach needs to be adopted so that costs can be shared and existing expertise disseminated effectively.

7. At a more detailed level, it is possible to recommend a number of techniques which have been found to be effective and relatively inexpensive:

- Computers can be used for a number of purposes including:
  - assessment of knowledge and measurable skills;
  - diagnostic testing of knowledge and skills (e.g. of first year intake)
  - word-processing (of reports) and spread-sheeting (for projects and laboratory calculations and business studies);
  - the management of courses and practical work;
  - the provision of rapid feedback of student progress (in the development of skill and knowledge).
  - computer conferencing for remote tutoring.
- Computer-based teaching of understanding needs an 'intensely supportive' environment if it is to be effective.
- Audio-vision - for the development of understanding and certain intellectual skills.
- CALM, (see Case Study 1) for the teaching of basic mathematical skills, though even CALM is improved with tutorial support.
- Video-tapes and CBT for the instruction and demonstration of skills. CBT can also be used for assessment of certain kinds of skills.
- Structured teaching texts (e.g. specially-prepared books) remain the most versatile and effective technology for the teaching of knowledge and understanding, provided students adopt a deep approach in their studies.

REFERENCES

1. The Engineering Council. (1995) *Competence and Commitment.* 10 Maltravers St, London.

2. *NVQ Criteria and Guidance.*, NCVQ (Employment Department), January 1995.

3. *Competence & Assessment; The Place of Knowledge and Understanding in the Development of NVQs.* The NCVQ and the Employment Department, October 1994

4. Laurillard, D. (1993) *Rethinking University Teaching: a framework for the effective use of educational technology,* Routledge, London

   Committee of Scottish University Principals. *Teaching and Learning in an Expanding Higher Education System,* From SCFC PO Box 142, Edinburgh

   Zimmer, G. and Blume, D. (1992) *Open and Distance Learning with Computer Support,* BW Bildung und Wissen Verlag und Software GmBH, Nürnberg.

5. Hitchcock, C., Kaye, A. R. and Sparkes, J. J. (1992) "State of the Art in Open and Distance Learning" in *Open and Distance Learning with Computer Support,* BW Bildung und Wissen Verlag und Software GmBH, Nürnberg.

6. Lewis, R. (June 1986) "What is Open Learning" in *Open Learning* , pp 5-10

7. EPC Occasional Paper No. 6, (May 1993) *Developments in First Degree Courses in Engineering.*

8. EPC Occasional Paper No. 5, (December 1992), *Assessment Methods in Engineering Degree Courses*

9. Eraut, M. (1992) "Developing the Knowledge Base: A Process Perspective on Professional Education" in *Learning to Effect,* edited by Ronald Barnett, S.R.H.E. & the Open University Press, Buckingham, p.109.

10. Bloom, B. S., Krathwohl, D. R. and Masia, B. B. (1964) *Taxonomy of Educational Objectives; Part II: Affective domain.* Longmans, London.

11. Collins English Dictionary, (2nd Edition, 1986)

12. Downs, S and Perry, P. (1982) "Research Report: How do I learn" Journal of European Industrial Training, **6**, No.6, pp.27-32.

13. Barnett, R. (1994) *The Limits of Competence,* SRHE and the Open University Press, Buckingham, p. 111

14. Dunn, R, Dunn, K. and Price, G. (1981) *Learning Style Inventory Manual* Price Systems, Lawrence, Kans.

15. Pask, G. (1976) "Styles and strategies of learning", *The British Journal of Educational Psychology*, **46**, pp.128-148.

16. Marton, F. and Säljö, R. (1976) "On qualitative differences in Learning: Outcomes and Processes", *The British Journal of Educational Psychology*, **46**, pp. 4-11.

17. Gibbons J. F., Kincheloe W. R. and Down S. K. (1977) "Tutored Video-tape Instruction: A new Use of Electronics Media in Education", *Science* **195** pp. 1136-1149.

18. Wolpert, L. (1992) *The Unnatural Nature of Science*, Faber and Faber, London.

19. Forbes, D. A. and Spence, J. (1991) "An experiment in the assessment of a large group" in R. A. Smith (Ed) *Innovative Teaching in Engineering*, Ellis Horwood, Chichester, pp 102-107

20. CALM. Numerous publications. e.g. Beevers, C. E., Cherry, B. S., Foster, M. G. and McGuire, G. R. (1991) *Software tools for Computer aided Learning in Mathematics. Ashgate publishers, Aldershot UK.*

21. William Foster, Martin Greenhow and Trevor Walker, "Developing student-centred software" Dept of Maths and Stats, Brunel University."

22. Stokes, R. J. S. (1994) *Computer Assisted Learning in Engineering at the University of Humberside.* University of Humberside

23. Osbourne, R. J. and Wittrock, M. C. (1983) "Learning Science: a generative process". *Science Education.* **67**, (4) , pp 498-508

24. Driver, R. and Easley, J. (1986) "Pupils and paradigms: a review of the literature related to concept development in adolescent science students". *Studies in Science Education*, **13**, pp 103-122.

25. Biggs, J. B. and Collis, K. F. (1982) *Evaluating the Quality of Learning: the SOLO taxonomy.* New York, Academic Press.

26. Steinaker, N. W. and Bell, M. R. (1979) *The Experiential Taxonomy.* Academic Press, New York

CASE STUDIES

Introduction

Although a great deal of work is being done in developing and experimenting with new computer-based teaching methods in different subjects, it is difficult to find any in engineering which have been thoroughly evaluated and can therefore be fully recommended as effective. The one which seems to fulfil this requirement most successfully is CALM (Computer-Aided Learning in Mathematics), but even this has been made cost-effective for the mathematics department of Heriot-Watt University by the award of development grants. In addition it is continually being improved upon, so it is difficult, at any point in time, to state precisely what it is!

CALM is only intended to develop and test mathematical skills, rather than mathematical understanding. In other words, its aim is to develop competence in mathematics as a 'language', to be used mainly for purposes other than 'doing mathematics', such as underpinning of science and engineering or providing basic skills on the way to studying higher mathematics.

Two other case studies are also described mainly because two members of the Working Group have been involved with them and therefore know a good deal about them. One is entitled "Computer Assisted Learning in Engineering at the University of Humberside" and the other is a course on "Manufacturing Processes and Materials at Bath University". There are lessons to be learnt from them all.

Case Study 1.

CALM (Computer-Aided Learning in Mathematics)(20)

Contact: Professor C. E. Beevers at Heriot-Watt University

The first CALM project was completed in 1988 with the help of funding from CTI. It included 25 units of courseware dealing with differentiation, integration, an introduction to numerical methods and elements of ordinary differential equations.

The teaching strategy of each unit is constructed around

- Theory sections - to consolidate the conventional lecture
- Worked examples
- Motivating applications - including mathematical games and realistic problems
- Test sections - to enable students to assess their own strengths and weaknesses and to allow teachers to monitor individual progress.

Each unit involves about 2 to 4 hours work by the students.

The project received the BNFL prize for mathematics in 1993. The external assessors noted that "The CALM materials are much liked by the students who are positive and enthusiastic about its use". The University reports:

"The CALM software was originally piloted with one group of engineering students - mechanical engineers - who represent about one-fifth of the total group of first year students learning calculus at the Heriot Watt University. They did so well using the software that by 1988-89 we were running the computerised tutorials for over 200 students each week of a 25 week course. We compared the examination performances of both mechanical engineers and another (non-CAL calculus group) in both algebra and calculus. . . . We found a relative improvement of 15% between the calculus and algebra performances of the group taught by CAL methods."

It has been found that much improved results can be achieved by combining CALM with face-to-face methods. Thus the approach adopted in the teaching of first year students became as follows:

"1. Conventional lectures give students the basic information on a particular set of topics.

"2. The students then learn for themselves via the computerised tutorials available from the CALM software.

"3. We ask the students in tutorials to specify, as questions, their general difficulty areas within that week's unit. There is then a round up session devoted entirely to these questions.

"The management of learning through the use of a shrinking list of questions, naturally and directly yields vital formative evaluation data about the progress of learning."

A one-day intensive revision course for those who had failed their June exams in calculus was introduced, which combined work with the computers with remedial tutoring. At every stage during the day the tutors had a "snapshot of where each learner had reached in that particular topic - and so had the students". This teaching strategy was found to be very effective, and is now a part of the general application of CALM.

There were some technical problems with mathematical expressions, for example, to enable the computer to recognise different forms of correct answers to questions. For example if the right answer is 8/9, the computer must be prepared to accept such answers as: 8 / 9, 16/18, 1 - 1/9, +8/9, 0.889, etc.

The second CALM project began in 1989, funded by the DTI, and is at the level of Scottish Highers. It deals with such topics as powers, trigonometry, analytical geometry, differentiation and integration, vectors and elementary statistics. It also seems to be successful.

Comments by Brunel University(21)

At Brunel University, CALM (from Heriot-Watt University) and the more elementary CALMAT (from Glasgow Caledonian University) have been the basis of a continually developing system of teaching/ monitoring of first year mathematics. It is currently being used with "students of mathematics, electrical, mechanical, production and environmental engineering, special engineering, materials technology, design and physics, making a total of well over 500 students in three faculties". Testing is at the heart of the system being developed.

In the first five weeks of the first semester the system is used to build up a clear picture of each student's mathematical abilities, from which a personalised scheme of study can be designed. It also provides a knowledge of class ability so that lecturers can react accordingly.

To enable diagnostic testing to continue throughout the first year, CALM needs a more flexible system of testing to be included, for which 'Testmaker' (from Southampton University) is being incorporated into the Testmaker Authoring Shell (TAS) which allows lecturers to create their own tests for each unit.

Further additions to the software are being designed to (a) convert log-on IDs to student's real names, and (b) make possible displays of individual student's selected test results, or a full listing of them. The whole suite is referred to as Brunel's CALM-Menu system (CMS). Their conclusion following three years of trials and development is as follows:

> "We are convinced that the ability to monitor large classes of students with very diverse backgrounds, and to provide instantaneous feedback to both students and lecturers alike, can only be sensibly achieved via a monitoring system such as (CMS). Experience over the three past years has shown that learning can be enhanced by a combination of traditional lectures and computer-based testing, and this is popular with the students. Moreover, lecturers prefer teaching and real contact with students to late-night marking sessions and appreciate the benefits of the system."

Comments from UMIST

CALM is seen as providing an opportunity not only to monitor the mathematical competence of incoming students but also to bring them up to speed before they enter the university. Thus it is used as a self-study package (including self-assessment) for prospective students to prepare themselves for the maths test UMIST have found it necessary to introduce at the beginning of an engineering degree course.

In addition CALM fits into a general policy at UMIST of introducing some element of CAL into most engineering courses, using standard shells.

Comments from Essex University

Calm is not now being used, although it has been used for a trial period in the mathematics department. This may be due to the fact that the two members of staff who were using it have now left and interest has lapsed.

Comment by the Working Group

We believe that the success of CALM derives largely from its carefully designed teaching strategy and from the fact that it is concerned only with mathematics-as-a-skill. It is also valuable as a first step towards to a deeper study of mathematics. To extend CALM to deeper levels, where shades of correctness would have to be evaluated would present severe problems. It is significant that both Heriot-Watt and Brunel have have found it best to embed CALM within a lecturing/ tutoring framework, unless it is used mainly as a monitoring mechanism.

Case Study 2.

A First Year Course in Manufacturing and Materials

Contact: Professor Alan Bramley, Bath University

The following is Professor Bramley's own description of his experimental development at Bath University.

Common to all engineering degree courses, especially to those with a mechanical/manufacturing orientation, is an introductory unit on manufacturing processes and materials. In the School of Mechanical Engineering at the University of Bath, student feedback from cohorts of up to 140 students, over several years of 'conventional' teaching of the subject (adequately supported by videos and artefacts etc.) indicated quite clearly widespread dissatisfaction. Qualitative research indicated that the students arriving at the University via a BTEC route or otherwise having had some industrial experience felt that they already knew the subject, were bored with the lectures and subsequently absented themselves. They failed to recognise the more quantitative approach associated with degree level courses in this subject and as a consequence did not perform well in the subsequent examination of the subject. On the other hand many students fresh from A-levels found it difficult to accommodate the pace, and, interestingly, to interpret 2D illustrations of processes. Various permutations involving a more generalised scientific approach, a case study/ assignment approach, metals only, etc., were tried but to no avail.

Simultaneously, the University, through its centre for Continuing Education had developed considerable expertise in the preparation of Distance Learning Material for postgraduate courses. Coupling this background with a successful bid to the HEFCE under its Flexibility & Learning Initiative provided an opportunity to develop an 'open learning' approach. A pilot programme was launched replacing just ten lectures on manufacturing processes with a self-instructional workbook supported by videos, tutorials and artefacts on a Resource Centre. The Workbook was felt to be of a good standard in the context of open learning; adequate in-text exercises, self-assessment exercises; all with careful attention to layout. There was also an expectation that there might be a reduction in staff effort on formal presentations and a greater emphasis on the tutorial function.

The pilot exercise, involving half of the cohort, enabled a comparison of the two approaches to be made at the end of the first term. The examination results are shown in Figure 1 and clearly indicate the shift towards a more acceptable normal distribution for the 'open learning' students.

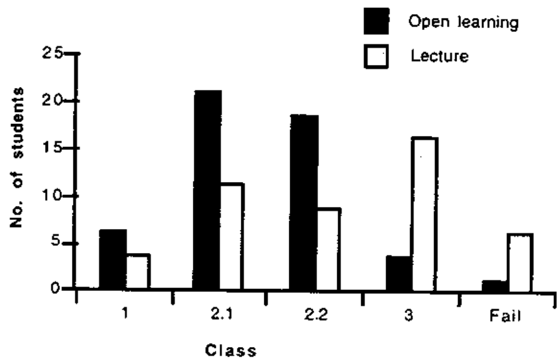

Figure 1. Comparison of Lecture and Open Learning methods

During the second term both groups were subjected to conventional teaching, and the end of year examination revealed no discernible difference between the two groups. However a detailed evaluation of the 'learning experience' of the two groups revealed the following:

Quantitative evaluation - lecture students

A majority of students, greater than 60%, responded as follows:

- lectures do not encourage their interest in the subject
- the course structure does not encourage them to take responsibility for their own learning
- lectures do not motivate them to study the subject
- lectures had helped them understand processes they had not previously understood
- there should be assignments for this subject
- there should be tutorials for this subject
- the hand-outs were clear and useful
- the content was presented at an appropriate level.

The group was split 50/50 ± 10% on whether lectures were presented in a clear and interesting way.

Quantitative evaluation - Open Learning students

A majority of students, greater than 60%, responded as follows:

- found the self-instructional style user-friendly
- the design of the course was suitable for them
- the course helped them gain factual knowledge
- the course structure helped them take responsibility

for their own learning

- the course helped them learn processes they did not understand previously
- the material had been thoroughly prepared
- they had support from their teaching team when they wanted it.

The group was split 50/50 ± 10% on

- the content being presented at an appropriate level
- whether too much background knowledge was assumed
- whether the material was presented in a clear and interesting way
- whether they had support from their work group if they wanted it
- whether studying this subject via lectures was preferable.

Encouraged by these results of the pilot exercise the open learning material was extended to replace 30 hours of conventional lectures. This was achieved through an inter-school collaboration between the Schools of Mechanical Engineering and Materials Science, reflecting the specialist requirements of the topic. Again, the process was supported by extensive evaluation. With the complete cohort engaged, the schedule comprised issuing the work book in two parts and indicating the locations of the referenced text and video material. The staff were in attendance for the one hour period each week with the aim of providing tutorial support, but attendance was at the 5-10% level. The end of term test was disappointing and the evaluation revealed widespread discontent with the open learning method.

During the second term the videos were scheduled to be shown during the class periods with the hope that this might provide some sort of focus leading to increased motivation of the students. Attendance improved on these occasions but there was minimal interest on the part of the students in engaging in the tutorial function. Come the end of the year the results were again disappointing. During the full implementation stage the students' disdain for the open learning approach seemed to be at odds with the evaluation of the pilot exercise. This may have been due to the perceived advantage of the 'open learning' students having a 'good set of notes' during the pilot exercise. With this disparity removed many of the students lacked the motivation to 'keep up' with the material.

Conclusions

It is desirable to teach the first year students the techniques of self learning, since they are certainly needed for project work in the later parts of engineering degree courses and certainly for post-graduation. The technique is however quite demanding of staff time; not only in preparing the original material but also providing the support. We are continuing with the open learning format.

Comments of the Working Group

The aims of the project were very ambitious, including as they did the development of students' understanding of aspects of materials processing. The case study brings out the difference between 'understanding what lecturers (or open learning materials) state', and 'understanding' as defined in the report. Being able to understand given explanations (in the sense of being able to 'follow' them) falls far short of the understanding which enables students to solve problems themselves in terms of the explanatory concepts which they need to have grasped. This is a weakness of lectures just as much as of prepared materials when teaching understanding is the aim. Videos and remedial tutorials do not help much, for reasons given in the report.

Furthermore, conventional examinations tend to test only knowledge and skills even when the questions are intended to assess understanding, as explained in EPC 5. A richer learning environment than either lectures or CAL is usually needed to enthuse students and to help them acquire 'understanding'.

Case Study 3.

Computer Assisted Learning in Engineering at the University of Humberside(24)

Contact: R. J. S. Stokes, MBE, University of Humberside

The primary aim of this development was "to identify, if possible, CAL material that could replace lectures and seminars rather than simply support them." Another aim was "to develop a CAL environment and materials that would support two types of learning - knowledge-based and investigative."

The project began by trying out commercial CAL packages, of which 11, mostly from abroad, were finally tested. Initial student feedback was very positive, but "as students made greater use of the material their questionnaire responses became increasingly negative". Careful analysis of student comments revealed that commercial CAL was not suitable for the planned undergraduate courses. The conclusions reached were that "both the material and the experience of using it must attract and motivate the students. . . . And any hint of it being a quick and easy way to reduce staff contact produced negative reactions on the part of the students".

Having arrived at a good appreciation of the nature of a desirable CAL environment, and having discovered that commercial material was unsuitable, "the only alternative was to explore ways of producing [programs] within the university".

Four authoring packages were reviewed: Toolbook, AuthorWare Professional, Icon Author and TenCORE. Icon Author was chosen because "it operated under a windows environment, was relatively easy to use, was inexpensive and could support the use of templates".

CAL programmes were produced to a well-thought-out plan, including a definite 'house style' enabling easy navigation. Templates were used into which the required features of a particular function could be fed (e.g. instruction, assessment and glossary). Continuous assessment was integrated with the teaching material to give students "frequent and rapid feedback" about their learning, and to "give staff effective means of monitoring performance and identifying problems". The authoring system allowed for either multiple choice questions or one word or single number answers. The team opted for multiple choice answers.

Once the material to be converted to CAL had been selected by the production supervisor and the lecturer, a good set of notes prepared (preferably in electronic form) and the learning objectives written, the 'production team' was able to prepare programs at a rate of about 50 man-hours per hour of material including about 10 hours of lecturer's and other part-time staff. The full-time team ideally consists of three members: one to produce the story-boards, one to produce the CAL programs and a third to produce the diagrams and animations. Degree students on their placement year were ideal. Part-time members included the production supervisor, editor, lecturers and technical support personnel.

In addition to the CAL material and monitoring arrangements, students are provided with "a well-designed workbook or other documentary material integrated with the program" and "seminar or tutorial support that is seen by students as targeted at their needs". Feedback showed that these additional items are important.

The testing of commercial material began in 1991, production of new material started in 1993 and by August 1994 ten CAL programs had been produced. "The results of trials were very encouraging. Over 75% of students thought that CAL could replace lecturing effectively and there was a general preference for the CAL approach".

The latest evaluation (Oct 1995) shows that the material is still well-received by the students, with no reduction in its popularity. About 160 hours of material has been prepared for use in 3 courses in 5 semester-length units. However, "The continued popularity of the CAL is attributed to the development of an 'Intensely Supported Environment'". This has caused an increase in marking which is not popular with the staff. Attempts are being made to reduce this workload using Computer-Based Testing and peer group assessment. A group of HND students were given the choice of continuing with CAL or have "the material delivered through traditional methods. The students unanimously elected to continue with the CAL!"

Comment by the Working Group

The most striking finding of this project is the need to back the CAL programs with an "Intensely Supported Environment (ISE)" if student motivation and support is to be maintained. The implication seems to be that a rich learning environment is needed to achieve this kind of learning, namely "knowledge-based and investigative". The extent to which this development at Humberside teaches understanding - as defined in the report - has not been investigated, but the popularity and effectiveness of the programs suggests that a further study of them would be worthwhile.

Appendix B

Brief comments on other methods of analysing the teaching and learning processes.

The main reason for our preferring the EPC's Taxonomy of Learning to other methods of analysing learning is that it models the learning process in such a way that the different elements of the model map well on to different ways of teaching. It is true that other analyses frequently refer to 'understanding' or 'knowledge' or 'skills', for example, but rarely explain what these terms mean or how they relate to teaching methods.

- Most recently, Diana Laurillard(4), in *Rethinking University Teaching* regards 'learning' as mainly a matter of developing 'understanding' (as defined in our taxonomy). She describes a 12-stage 'conversational framework' to identify "the activities necessary to complete the learning process" (See pp. 103 and 119) which includes much interaction between teacher and student. But she adds that the sequence of steps "is not normally applicable to learning through experience, nor to 'everyday' learning, nor to those training programmes that focus on skills alone"! (We regard these and other ways of learning of importance even in higher education). She bases her analysis of teaching methods on the extent to which each method can help with her 12 steps. Our view is that although teaching 'understanding' is a complex business and demands much more activity on the part of the student than just absorbing information, her 'conversational framework' is too specific. Certainly, 'reflection' by students on their learning experiences is important, but regarding it as an 8-stage internal 'conversation' is not how most people think of 'reflection' and it stretches the meaning of 'conversation' too far. Advocating 'reflection' is only another way of saying that students should have 'active minds' or 'adopt a deep approach'. With a 'reflective' mind, even reading a well-written text or attending a good lecture, can be very effective.

- The Report of the Committee of Scottish University Principals(4) similarly ignores the development of 'skills' and 'knowledge' and 'know-how', as defined in our taxonomy, and concentrates on 'understanding'. It states that "the development of a thorough conceptual understanding involves a series of learning phases", but they are quite different from Laurillard's, namely: "orientating, motivating, presenting, clarifying, elaborating, consolidating, confirming" (p.6). The report emphasises the need to encourage the 'deep approach' to learning, but discusses future educational methods mostly in terms of means of "delivery". It suggests that "the spectrum of teaching/learning support" ranges from imparting information to managing the complete support process. Yet "complete support" seems to go no further than "remedial teaching". We believe that acquiring understanding involves greater student mental activity than this.

- In *Open Learning and Distance Education with Computer Support* (4) there are two parts: Part 1 adopts a similar methodology to our's, with 11 case studies briefly analysed. Part 2 adopts a different approach again, and uses a "conceptual model for description and evaluation of computer-based learning systems (CBLS) which includes four fundamental components: subject matter component, learner component, pedagogic/didactic component and information technology component". Within this model "three central dimensions were highlighted: self-regulation, individualization and interactivity." The analyses also refer to "factual knowledge, skills and higher order qualifications", where the latter presumably equate to our 'understanding and know-how'. However, despite this overly structured "conceptual model" the comments contained in the report about different forms of CBLS complement those given in this report.

- As regards the conceptual development, upon which 'understanding' depends, there is renewed interest among cognitive psychologists in 'constructivism'. This asserts(23) that "the brain is not a passive consumer of information. Instead it actively constructs its own interpretations of information and draws inferences from them". This may be satisfactory in some fields, but not in science and engineering. As Rosalind Driver(24), puts it, with reference to school teaching, "pupils need to be helped and guided to adopt the scientists 'spectacles', and the challenge to curriculum developers is to do this in a way that neither undermines pupils' confidence in their own abilities to make sense of learning experiences, nor gravely misrepresents scientific ideas". This applies equally to higher education.

It is true that in some professional fields, unconstrained 'constructivism' is helpful. If the learning goals are limited to the development of 'know-how' it is normal for students to construct there own way of making sense of their experiences. It is also appropriate in contexts where well-formed opinions are to be expected, as in politics for example, and where disagreements rather than mistakes are normal. But it is essential in science and engineering (and in aspects of medicine and education too), to ensure that students internalise the accepted explanatory concepts before they construct new ones of their own. Successful scientific 'constructions', like Newton's, are rather rare!

- A number of taxonomies have previously been proposed but none have tried to distinguish between different kinds of 'learning', as now seems to be essential. *Bloom's taxonomy* distinguishes between 'objectives' and so is oriented towards that which is readily testable, and consequently does not include 'understanding' as here defined. (Note that 'understanding' is not the same as the sum of all specifiable objectives.) The *SOLO taxonomy* (25) classifies kinds of responses to questions, but does not relate them to the underlying kinds of learning, and so overlooks the fact that 'high level' responses to questions can be achieved mainly from memory - as often happens in exams - without much understanding. Similarly, *the experiential taxonomy*(26) distinguishes between different kinds of learning experience, but refrains from inferring the kinds of learning which are likely to result.

- In general we believe it is essential to look behind and beyond educational observables to the 'kinds of learning' which underpin them, if the analyses of these observables - whether they are fulfilled objectives or learning experiences - are to contribute to improved teaching methods.

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Appendix C

Terms of Reference of the Working Group

1. To define 'Open Learning' as it might apply to engineering education.
2. To identify the various kinds of Open Learning which might be effective in engineering education.
3. Through an analysis of learning goals, costs and academic standards, to specify some clear criteria by which different methods of Open Learning might be evaluated.
4. To apply the above criteria, both in theory and in practice, to a range of Open Learning methods.

Appendix D

Membership of the Working Group

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