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The Future of First-degree Engineering Courses in the United Kingdom

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The changes in engineering degree courses proposed by a Working Group of Engineering Professors in the United Kingdom are outlined. They include a reduced content of factual material and specialized skills, and a greater emphasis on transferable skills, such as communication, integrative and interpersonal skills, and on the understanding of basic principles. The importance of stating educational aims in some detail so that assessment, teaching and learning methods can be matched to them is explained. Techniques for doing this, and for matching teaching methods to students' preferred learning styles, are outlined.

INTRODUCTION

A WORKING Group of the Engineering Professors' Conference (EPC), under the Chairmanship of Professor Graham Ellison, has been discussing what can be done to improve engineering education in Britain and to make it more appropriate to modern needs. We have produced a report entitled 'The Future Pattern of 1st Degree Courses in Engineering' [1], an updated version of which provides the background to this paper. The reasons behind the proposals for change include the need to increase student–staff ratios: the need to meet better the requirements of industry and other employers; the need to motivate students better and to broaden their education; and recognition of the importance of maintaining academic standards in teaching, research and other kinds of scholarly activity. Evidently there are many factors to balance one against the other in arriving at proposals that would lead to an all-round improvement.

The term 'teaching' is interpreted as 'the creation of environments in which students can learn effectively', which implies that it is much more than just good lecturing. It involves being able to use effectively the normal facilities provided by universities, including lectures, textbooks, libraries, computers, structured educational texts for individualized learning, small group tutorials of various kinds, problem classes, laboratories, proctoring, and individual and group projects, etc. In practice this means being able to match these teaching methods to stated educational aims.

The Working Group has accepted two constraints. Firstly, that its proposals should not modify the present arrangements in which engineering departments offer degrees oriented—to varying extents—towards their own particular fields (e.g. chemical engineering or electronics). Secondly, that it is essential to ensure, through consultation with the UK Engineering Institutions, that 3-year first degrees, as well as 4-year first degrees, should continue to be accredited or 'approved' and recognized for professional purposes by the appropriate institutions.

A key aspect of the proposed changes is a reduction of the factual and analytic overload, which at present characterizes most engineering degree courses. The continuing growth and development of engineering has tended automatically to lead to this state of affairs. The justification for reducing the content of information to be remembered is that new knowledge generally becomes rapidly outdated and can quickly be acquired when needed. The Working Group's main proposals are therefore to require students to concentrate on the key aspects of engineering that take time to learn, namely transferable skills and the understanding of fundamental principles, so that they need not spend so much time simply absorbing knowledge. In this way the Group believes that graduates will become better able to adapt to the rapidly changing working environment which will confront them as engineers.

An additional key aim of the first-degree courses is to prepare and motivate students to become life-long learners. The EPC have accepted that it is sensible to continue with 3-year first degrees even though it is clear that nowadays 3 years is insufficient to prepare graduates for many kinds of engineering work. But it is also clear that appropriate kinds of engineering education can differ markedly from one kind of job to another. Students' fourth (and later) year's education or training need not necessarily be a direct continuation of their first 3 years; further training in industry, or in another country, or at another educational institution, for example, is likely to be more appropriate for some students than a fourth initial year.

An important corollary of this policy is the need for an increased emphasis on both continuing education, especially distance education, and independent learning. Both of these aspects of engineering education are therefore emphasized in the EPC proposals.

AN ANALYSIS OF THE EDUCATIONAL PROCESS

In essence, the EPC proposals concentrate on the need for each university to be clear about its educational goals and to be able to match its educational methods to these goals. Thus there are two aspects of 'quality' in higher education, both of which are summarized in the following definition of it:

> Quality in engineering education means defining worthwhile learning goals and enabling students to achieve them.
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> (i) Defining worthwhile goals in engineering involves paying attention to the expectations of society, to students' aspirations, to the demands of industry, to the requirements of professional institutions, to the fundamental principles of the subject, to practical limitations, etc. There are many possible and valid interpretations of 'worthwhile', and educational institutions and aspiring students therefore need to be clear about the ones they adopt.
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> (ii) Enabling students to achieve these goals involves making use of research into how students learn and building on successful teaching experience, both of which may require professional development for most teachers. It also involves establishing quality assurance procedures to ensure that standards of all kinds are maintained and improved.

For this programme of development to be meaningful it is necessary to distinguish between different kinds of teaching and learning, so that goals can be expressed in terms of them and so that teaching and learning can be matched to them. The minimum set of kinds of learning in the 'cognitive domain' consists of *knowledge*, *skills*, *understanding* and *know-how*. That is, these kinds of learning differ significantly not only as regards their inherent characteristics, but also as regards the ways they should be taught, learnt and assessed. The 'affective domain' of learning, comprising attitudes, values and especially *motivation* to learn, has also to be attended to in all engineering education, because without motivation little learning is likely to take place, and appropriate values and attitudes are key aspects of good engineers.

Unfortunately common usage has blurred the meanings of such terms as 'knowledge', 'skills' and 'understanding' to such an extent that they are unusable as they stand for educational analysis. They are thus given specific meanings in this paper. The same kind of distinctions were long ago accepted in science, where words like 'work', 'force', 'energy', 'field', etc., were given clear scientific meanings to distinguish them from everyday usage. The concepts in the cognitive domain are defined as follows.

- *Knowledge* is 'information that has been memorized and can be recalled in answer to a question'. Information does not become knowledge until it is well remembered. (Quizzes on radio and television are all about this kind of learning.) If students are interested and understand, their learning of knowledge can be almost instantaneous. To teach knowledge it is necessary to present the information in a way that students can understand, and (if necessary) to motivate them, for example by making it relevant, by frequent testing and by teaching simple study skills.
- *Skills* are 'things people can do without thinking too much about how to do them', such as walking, discussing, writing, doing applicable mathematics, typing, playing tennis, 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. They are all taught by instruction and demonstration, followed by providing opportunities and incentives for practice. Unlike knowledge, skills cannot be acquired quickly however interested the learners might be. Note that it is usually easier to *know* what a good performance is like, or even to *know how* to do things, than to *be able to perform well* oneself, so a good deal of self-monitoring of skills is possible. Skills vary in the extent to which they deploy knowledge and understanding in their successful execution: 'designing' in engineering can demand a good deal of both, though 'walking' requires neither!

  From the point of view of the assessment of student skills it is worth distinguishing between 'measurable' and 'complex' skills.

  - *Measurable* skills are those for which correct performance can be clearly specified; these include applicable maths, spelling, grammar, vocabulary (but not style) in any language; using computer software packages; etc.
  - *Complex* skills include communication and interpersonal skills; designing; management; the integration of knowledge, understanding and skills in problem solving; etc.

  Measurable skills can easily be tested, but the assessment of complex skills needs judgement on the part of the examiners.
- *Understanding* can be defined as 'the capacity to use concepts creatively in explanations, in designs, in correcting errors, in asking searching questions, in doing back-of-the-envelope calculations, etc'. It is the basis of 'thinking', especially logical thinking. There are no direct tests of understanding since it concerns the way inputs

to the brain are transformed into outputs. Only inputs and outputs are directly observable, so understanding has to be inferred from the way people tackle complex problems. There are two parts to the learning of understanding.

(i) grasping the abstract concepts upon which understanding depends (such as energy, electromagnetism, quality, productivity, etc.); and
(ii) applying these concepts in arriving at good explanations, arguments, designs, fault corrections, etc.

There are many levels of understanding, from simply comprehending the meanings of words to having the capacity to deploy the most advanced and abstract concepts in problem-solving. The learning of understanding requires a rich educational environment in which the concepts forming in students' minds can, so to speak, be illuminated from different directions. They need to be put in context, defined, read about, discussed, applied in problem-solving, written about, explained to others, etc., before they are fully internalized.

- *Know-how* should not be confused with *understanding* even though they both provide the basis for problem-solving. 'Know-how' is acquired through apprenticeship or continued contact with particular kinds of problems. Many experts in particular fields (e.g. doctors and engineers) have acquired, through years of experience, a good deal of know-how, which they cannot fully explain. Computer-based 'expert systems' attempt to capture this know-how so that others can benefit from it. Understanding, by contrast, makes use of concepts and explanations rather than experience in problem-solving. It can therefore cope better with completely new problems, but less well with familiar ones. The distinction between understanding and know-how is important since they are acquired in very different ways.

The EPC proposals emphasize the teaching of understanding—plus any relevant knowledge and skills—rather than know-how, partly because know-how takes too long to acquire: partly because, when mishaps occur, ignorance of accepted basic scientific and engineering principles can be an indictable offence; and partly because know-how is more specialized and can quickly become outdated. It is true, of course, that fully capable engineers need both understanding and relevant know-how, but the function of first-degree courses must primarily be to develop the former.

Note that relevant skills and understanding take time to acquire and cannot, like knowledge, simply be 'looked up' in books or journals when required. It is thus important that they are taught over the whole period of the first degree.

The importance of making these distinctions between different kinds of learning is simply that they call for different teaching and assessment methods on the part of the teachers and for different learning methods on the part of the students. Both groups of people are, however, likely to need help in grasping what is expected of them, which is in any case an essential part of 'quality assurance'. As Edwards Deming said, 'Everyone doing their best is not the answer. It is first necessary that people know what to do.'

THE PROPOSED COURSE-DESIGN STRATEGY

Research has shown that quality learning is greatly improved if students can be persuaded to adopt a 'deep approach' to learning. This implies an intention to understand, to look for meaning, to compare explanations with experience, etc. This is in contrast to the 'surface approach', which implies an intention to memorize information, practise measurable skills, pass exams, etc., without attempting to grasp the underlying concepts of the subject. The factors that encourage or even force students to adopt the surface approach are well known; they include an overloaded curriculum; assessment methods that reward knowledge recall and the exercise of measurable skills; absence of personal involvement; etc. In order to encourage the deep approach and for the purpose of improving teaching without increasing the workload of staff, the EPC proposals involve the following:

1. Reducing the amount of factual material for students to memorize, so that it includes only that which helps students' acquisition of transferable skills and understanding.
2. Concentrating on teaching understanding and transferable skills—including complex skills such as communication and interpersonal and integrative skills—so that students become more flexible and able more quickly to turn their hands and minds to new problems as they arise.
3. Reducing the amount of formal analysis. Much of this can now be done with the aid of computers and in any case formal analysis does not necessarily lead to a better understanding of relevant concepts.
4. Teaching only the mathematics, economics and aspects of science that are applicable to their chosen kind of engineering degree. In many cases mathematics should be thought of more as a tool or vehicle for creative thought and analysis—like languages—rather than as an academic discipline. More advanced science and mathematics can be learnt later by those who need it;
5. Interleaving formal teaching with problem-solving activities, to show the relevance of advanced concepts, to help motivate students, to prepare them for independent study, to give practice at holistic and integrative skills.

6. Offering fewer final-year options so that more time can be spent on essentials. Some of the existing options might form the basis of postgraduate modules.
7. Restructuring the exams so that knowledge and measurable skills are not tested in the same examination as understanding, and ensuring that students are aware well in advance of this change.
8. Providing staff development as well as student development in appreciating the different types of teaching and learning that may be required.
9. Ensuring that students are capable of independent learning—e.g. by making use of some of the methods used in distance teaching, where student–tutor contact is reduced to a minimum.

Reducing the factual and analytic content of degree courses is not intended to lower standards; on the contrary, the proposed change in emphasis towards understanding and transferable skills is intended to raise both the standard and quality of engineering courses. It is only through the application of these strategies that it remains sensible to accept 3-year degrees as an adequate preparation for future engineers. Even so, graduates, before becoming professional engineers, will almost always need to proceed to further education and/or training: in industry, in a foreign country, at an institute of higher education either as a direct continuation of the first degree or after a break or in a different university.

EXAMINATIONS AND OTHER FORMS OF ASSESSMENT

The nature of examinations has a profound effect on the kind of learning that occurs. This implies that examinations can be used to steer student-learning in a desired direction. Research [2] shows that most present-day exams do not require students to 'understand' a subject, despite most teachers' best intentions. Students find that good marks can more easily be obtained by concentrating on memorized information and well-practised measurable skills (e.g. of calculation) than by trying to understand. Indeed, students who have concentrated on understanding their subject often find themselves at a disadvantage on the limited time allowed in an examination. Forms of assessment that are better designed to test understanding are therefore needed, otherwise students, being 'strategic learners', will continue with their present optimum strategy of remembering 'model answers', question spotting, practising specialized skills, etc.

The differences between testing in the three main cognitive domains can be summarized as follows:

- *Testing for knowledge* is a matter of testing for recall by questioning. Multiple-choice questions or descriptive essays are often quite appropriate. For essential knowledge a high pass mark, with no grading, may well be justified (i.e. 'criterion-referenced' testing).
- *Testing for skills* is a matter of setting appropriate tasks and of judging students' ability to perform them to required standards. For essential *measurable* skills, criterion referencing with a high pass mark may well be appropriate again. The assessment of *complex* skills requires experienced judgement, so the grading of students relative to one another (i.e. 'norm referencing') is likely to be more appropriate than criterion referencing. Projects provide the usual way of testing integrative skills as well as of a variety of other complex student characteristics, such as responsibility, persistence, initiative, ingenuity, etc.
- *Testing for understanding* is a matter of setting challenges that are new to the students and to which the concepts they have internalized are relevant. The tests should be such as to ensure that factual knowledge and well-practised skills alone cannot provide satisfactory answers. The aim is to get students to 'think', or, to quote Bruner, to 'go beyond the information given'! Oral examinations can provide the kind of challenge needed but may be too time consuming in practice.

The EPC report suggests a number of ways in which understanding, rather than knowledge and skills can be assessed.

HOW SHOULD THE MATERIAL BE TAUGHT?

The EPC report also outlines the various ways in which the conventional teaching methods can be adapted to facilitate different kinds of learning. For example

Small group tutorials can be used for almost any kind of learning but should take different forms depending on the educational aims [3].

- *Remedial tutorials* consist mainly of the tutor answering students' questions. They concentrate on correcting students' errors or with helping them to overcome specific difficulties. They are good for teaching knowledge and skills but do little to advance understanding unless tutors help students to sort out their own difficulties, rather than sort them out for them.
- *Tutorial classes* are also dominated by the tutor, but take the form of interactive teaching of the kind that is difficult in lectures (though it can be done [4]) but is common in high-school teaching. They are time consuming but can be effective for any kind of learning, provided they do not turn into mini-lectures.
- *Group working* is more student-centred in that students are encouraged to do most of the talking. The function of the tutor is not to answer

students' questions but to facilitate student discussion and argument—particularly about the application of concepts to modelling, problem-solving and back-of-envelope calculations. It is often better, when learning understanding, for students to talk about what they believe they *do* understand than for them to hear again an explanation by their tutor of what they believe they *don't* understand. Indeed it is often better if the tutor cannot—or does not—answer students' questions. There are various techniques for running such tutorials described in the EPC report.

With all kinds of tutorials it is important to avoid the common tendency for tutors to give mini-lectures.

Lectures can fulfil many useful functions in an educational system, though they do not themselves provide a very good learning environment for teaching skills and understanding. Note that 'understanding a lecturer' is very different from 'understanding the subject' being taught. Although the lecturer may have been very clear, it is not to be expected that students will have fully grasped the concepts being introduced, or will have developed any skills during a lecture—except perhaps the skill of note-taking! It is mainly factual information that can be absorbed, provided the students are not bored. Nevertheless, as part of a rich learning environment, lectures are useful for various important purposes, such as: spelling out the syllabus; enthusing students for the subject; introducing concepts, putting them in context and showing their importance; demonstrating intellectual skills of communication, analysis, design, etc.; helping students to pace their work; giving them an 'identity' and a feeling of 'belonging' within the whole complex educational system; communicating relevant knowledge and describing 'case studies' or specific applications to which various key concepts are relevant; etc. Most of students' conceptual learning and acquisition of skills takes place in activities other than lectures. Note especially that these aims can be achieved with many fewer lectures than are currently given in many engineering courses.

The key skill that distinguishes engineers from many other kinds of graduates is their ability to think integratively or holistically. It is with the development of this skill that problem-solving projects and mini-projects throughout a course should be mainly concerned. Since projects can be very variable as to their conceptual depth, they do not always provide an effective way of assessing or teaching understanding.

In a similar way, other teaching methods can be adapted to achieve different educational aims. Such methods include: the use of undergraduate textbooks, problem classes, proctoring and peer teaching, laboratory activities, computer-based teaching, computer conferencing, video tapes, audio tapes, telephone conferencing, dial access by telephone, etc. The EPC report gives further explanations of how a number of these methods can be adapted to specific educational aims.

In addition to matching teaching methods to specified or general educational aims, learning is improved if teaching styles cater for the fact that students have different learning styles—at least where the learning of understanding is concerned.

For example, some students are 'serialist learners' and like to follow a logical, well-structured progress through the subject they are studying. Others are 'holistic learners' and prefer to take an overview of the subject and then fill in the details in their own way [5]. Books, for example, are naturally serialist in character, so that it is helpful for holist students if 'signposts', summaries, redundancies, explanatory captions to figures, etc., are included. Similarly, projects are naturally holist in character so guidance should be made available to help serialist students to structure their approach to the problem-solving required of them.

Some students are 'verbalizers' and learn best through words. Others are 'visualizers' and find diagrams and illustrations particularly helpful. Yet others are 'doers' and learn best through hands-on experience. It is not practicable to sort students according to their learning styles and provide different appropriate teaching styles for each cohort; but it is possible to provide alternative learning environments for the more difficult concepts so that students can to some extent help themselves.

CONCLUSION

Students are normally interested in gaining good marks, so methods of assessment can be used to steer them towards important learning goals. But if students are to benefit, any changes must be well planned and announced before the corresponding teaching methods are changed too much. Present teaching methods, with their emphasis on knowledge and measurable skills, are well matched to typical examination methods. Changing teaching methods without introducing corresponding changes in assessment methods could be disastrous. For these changes to be effective it is essential that students understand the ideas behind them. An induction course for students, covering much the same ground as this paper, is therefore an important part of the process of change. The main purpose of such a course would be to enable students to take better control of their own learning, whether as independent learners or as 'consumers' of the kinds of teaching on offer.

Similarly it is important that teaching staff understand the rationale behind these proposed developments. Staff development may well be needed. Unfortunately in the United Kingdom, energy devoted to staff development and improvements in teaching is not yet well rewarded in higher education. But the UK Government is now beginning to take seriously the concept of 'Quality Assurance in Higher Education' (about which there is another EPC report), and since staff development is high on the agenda of quality assurance procedures, there is hope that the present systemic constraint on advances in educational activities will be relaxed before long.

Finally, it is clear that only if the kinds of changes outlined in this paper are implemented is it sensible for the 3-year engineering degrees, common in the United Kingdom, to continue to be an adequate first step in higher education towards the formation of fully capable engineers. But even if these changes are implemented, they do not remove the need for the further training and education of engineers beyond 3 years, in appropriate environments, depending on the kind of engineering to be undertaken.

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