

Effective Teaching and Learning in Higher Education, with Particular Reference to the Undergraduate Education of Professional Engineers*

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This paper discusses current knowledge about effective teaching and learning in higher education and the implications for undergraduate engineering education. The author considers that aspects of the traditional model of engineering education, such as the widespread use of lectures, the overcrowded content and the assessment methods used, do not lead to high quality learning. Problem-based learning is one approach to overcoming these deficiencies; its advantages are discussed and some examples of its implementation are given.

INTRODUCTION

UNDERGRADUATE ENGINEERING education has ‘changed very little over the last half of this century’ [1]. Regular reviews have taken place in many countries, but these have tended to focus on the subject content of degree courses, and its relevance to the needs of engineering employers [2]. However in the 1990s, pressure for more radical change began to build, for instance, in the United Kingdom [3], Australia [5], the United States [5] and New Zealand [6]. This debate forms the background to this paper.

One of the principles underlying this paper is that an understanding of how students learn is necessary in order to judge the effectiveness of current practice and to make rational decisions for change. Accordingly, current knowledge about effective teaching and learning in higher education will be described and discussed, with particular reference to the current norm in engineering education. Problem-based learning, which is an alternative to the traditional way of organising engineering education, will then be introduced. First, however, the factors which are driving the present calls for change will be summarised.

Reasons given for the need to change engineering education fall into three broad areas:

- changing needs of employers;
- changing needs of students;
- wider economic and political changes.

Rapidly changing technology means that employers need more flexibility and less specialisation in graduates, together with an increased capability

for design and innovation [6]. Employers also want graduates who can work cooperatively, with good communication and management skills [2]. The changing needs of today’s engineering students are a result of the movement from an elitist to a mass education system, which means that students are less prepared for university study than in the past [7]. Taken together, changing needs of employers and students results in pressure to include more content into engineering degree courses. The difficulty then becomes one of how to make room in the already overcrowded syllabus, which typically leads to debates about what to take out and what new material to include.

At the same time, a changing political and economic climate means that universities are under pressure to ensure that declining resources are used in the most efficient and effective way [8]. In addition, increasing student/staff ratios place extra pressure on academic staff time, thus emphasising the need for such time to be spent as efficiently as possible [9]. Increasing recognition in universities of the importance of teaching also places responsibility on engineering academics to examine the effectiveness of current teaching practices [2]. It is timely, therefore to review what the higher education literature tells us about the learning outcomes of engineering students.

CONCEPTIONS OF LEARNING

A general complaint among engineering lecturers (indeed among many lecturers in higher education) is that [10]:

1. Students simply fail to learn much of the material presented to them.

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2. They pass exams even though they demonstrate misconceptions about fundamental concepts.

In addition, there is evidence that the overloaded content of engineering courses leads to many engineering students taking an instrumental approach to their studies. This is marked by a motivation to pass exams in order to obtain a degree (and hence a job), rather than being driven by an interest in learning [11]. This is a dilemma if we wish our graduates to continue learning when they leave university.

Ramsden [10] notes that there is often a discrepancy between what lecturers say they want their students to learn and what students actually learn. He argues that, in order to understand how this happens, we must study our educational practices through the eyes of students; only when we understand learning at this level can we improve the effectiveness of our teaching. One way of reaching such an understanding is through a qualitative research method known as phenomenography, which uses in-depth interviews to find out the different ways people interpret and understand phenomena in the world about them. An underlying principle of this research method is that people's understandings affect their behaviour; thus a person's conception of learning would affect their approach to learning.

Phenomenographic research has shown that, when learners are asked to talk about what they understood by learning, their replies can be classified into five different conceptions of learning as follows [12]:

1. increasing knowledge;
2. memorising and reproducing;
3. acquiring facts and skills that can be applied;
4. understanding;
5. interpreting reality in a new way.

In the first three conceptions learning is something external to the learner, that is, something that is done to the learner. In contrast, conceptions 4 and 5 emphasise the internal aspects of learning, so that learning involves changing the way one relates to the world. This system of conceptions is a hierarchical one; for instance, students with conceptions at level 4 or 5 do see that learning involves increasing one's knowledge, but they also believe that it is necessary to understand the knowledge.

LEARNING APPROACHES

Research has shown that students' conceptions of learning are important factors in determining learning outcomes, but they are not the only factor [10]. A second factor is the approach that students take to learning a particular task. Two main categories of learning approach have been identified: a deep approach and a surface approach. In a deep approach to learning, the student looks for underlying meaning and structure, taking a holistic

view. In contrast, a surface approach focuses on discrete pieces of knowledge, without attempting to integrate them. Thus the surface approach is about 'learning *just* the unrelated facts' while the deep approach is about 'learning the facts in relation to the concepts' [13].

An important thing to note here is that the approach to learning is not a fixed characteristic of an individual, thus it is incorrect to speak of deep and surface learners. Rather, all learners are capable of using both deep and surface approaches, and it is their perception of the demands of a task that largely determines which approach they actually use. However, there *is* a general tendency for an individual to prefer a particular approach [10]. Students who see learning as increasing knowledge or memorisation, that is, who see the process of learning as external to themselves, tend to use surface approaches and their focus is on satisfying assessment requirements [10, 14].

Conversely, students who have higher conceptions of learning are more likely to use deep approaches [10]. Such students see learning as an internal process, one that involves them acting upon the material in order to give it some meaning to themselves. This process of 'making meaning' is essential to the learning process, according to the socio-constructivist theory of learning. This theory argues that learning involves the construction of knowledge and that learners must actively seek to make meaning from their experiences by relating new information to what they already know, by reflecting on new experiences and hence integrating new information into their existing models of knowledge. This is to be contrasted with the more traditional theory of learning as knowledge transmission, whereby knowledge is a fixed, objective entity which can be transmitted from the teacher to the learner, for example during a lecture.

Socio-constructivist theory would suggest, therefore, that deep approaches to learning are more likely than surface approaches to lead to understanding and enduring learning and research supports this view. Students who use a deep approach to learning gain higher grades and are more likely to remember material and to be able to apply it to unfamiliar situations [10]. In contrast, the use of a surface approach is associated with low quality and ineffective learning; short-term goals, such as passing tests, may be achieved, but much of what was 'learned' is quickly forgotten. Ramsden notes that surface approaches may permit students to acquire 'imitations of subjects' that is, to pass exams but not to gain a true understanding of the subject [13].

A study of learning approaches in a class of mechanical engineering students in Hong Kong showed that a surface approach was associated with poor grades and greater hours of independent study time [15]. The latter was a result of the inefficiency of the surface approach. However,

use of a deep approach did not result in good grades unless it was accompanied by sufficient work. This supports the comments of other authors that a well-structured knowledge base, appropriate to the subject being studied, as well as a deep approach, is necessary for understanding [10, 16]. However, a surface approach ‘. . . can never lead to understanding’ [17].

Learning approaches are related to learning outcomes in terms of attitudes to studying as well as grades. The use of a deep approach leads to satisfying and enjoyable learning, with a sense of challenge and involvement [10]. These are important attitudes if students are to become lifelong learners. In contrast, the use of a surface approach tends to make study a drudgery; it is linked to negative attitudes to study and is associated with feelings of ‘resentment, depression and anxiety’ [18]. Further, the link between learning approaches and study attitudes is reciprocal, so an intrinsically interesting task can lead to the use of a deep approach [10]. Conversely, students are likely to use a surface approach to deal with a routine, uninteresting task.

If it is so important to use deep approaches, why not teach students to learn in this way? Unfortunately, attempts to do this have been unsuccessful, largely because they did not change the learning context, that is, the conditions external to the student for a particular learning task [10]. These conditions are set mainly by the teaching methods, content and assessment methods in a course. However, the situation is more complex than this, for it is each student’s perception of this context that matters, not what the lecturer intends the context to be. For instance, a lecturer may verbally encourage students to study for understanding, but if the course rewards the use of surface techniques by using assessment methods that require short-term retention of large amounts of material, then students will use a surface approach to learning. Teachers can never ensure that learners will use a deep approach, they can only arrange conditions such that they encourage the use of such an approach. This issue will now be considered in more detail, with particular reference to current practice in undergraduate engineering education.

THE LEARNING CONTEXT

Lectures

The lecture is still the main teaching method in engineering education; its use reflects a view of the learner as a passive recipient of knowledge and of teaching as the transmission of knowledge. Because of its structure, with one lecturer and many students, there is little chance of an effective interaction or two-way dialogue [19]. Although many lecturers work hard to establish such a

dialogue, it is in practice difficult to ensure that students actively engage with the course material to any meaningful extent. The widespread use of lectures sets up a context in which learning is external to students, thereby encouraging student dependence and passivity and the use of surface approaches.

Lectures are normally supplemented by laboratory classes and problem sessions. Again, the challenge is to set a context which encourages the use of deep approaches. For instance, it is often possible for students to take a surface approach to laboratory exercises by blindly following instructions [15]. Frequently, even in small groups, there are difficulties engaging students in the process, as they have been accustomed to being passive and resent being asked to take an active part in a class [20].

Course content

Turning now to course content, in the first two or three years of an engineering degree the curriculum is heavily biased towards engineering science subjects and mathematics. The obstacle to learning here is that students frequently do not see the relevance of much of this material, particularly if it is taught out of context [11]. A phenomenographic study of the learning conceptions and approaches of a group of civil engineering students found that, when the course content was perceived as irrelevant, students adopted a surface approach to study [21]. However, when students saw the content as connected to a civil engineer’s work, they were more likely to use a deep approach.

A second issue is the overload of content in engineering degree courses, which means that formal contact hours are very high. Thus students do not have the time to study course material after a lecture in order to assimilate it and understand how it relates to other course material. A number of studies have found an increasing use of surface approaches to study as students progress through their degree, and have associated this with the high workload of engineering courses [22, 23].

Assessment

Another aspect of the learning context of engineering courses is assessment, which frequently exacerbates the problem of high workload. Extensive in-course assessment can lead to students being overloaded with assessment tasks, which encourages the use of surface approaches [10]. Assessment, more than any other single factor, defines the curriculum for a student, because students focus on work which is to be assessed, at the expense of other work [24]. Consequently students are driven by the external demands of the assessment system, rather than by internal motives such as interest, and again this encourages the use of surface, rather than deep, learning approaches.

CHANGING THE LEARNING CONTEXT

Since the assessment system is such a powerful force in defining the curriculum for students, Elton and Laurillard [25] argue that 'The quickest way to change student learning is to change the assessment system'. Accordingly, one way to encourage the use of deep learning approaches is to set assessment tasks which test a student's understanding, rather than tasks which require memorising and reproducing knowledge or processes. However, if this step is taken in isolation, for instance in a terminating exam, students may not know how to approach such tasks [26]. Students need to learn how to integrate new knowledge and apply it to new situations and the pressure of an exam situation is not conducive to this.

Assessment needs to be seen as part of the teaching of a course, rather than as an add-on [10]. It is more useful, therefore, to consider changes to the learning context as a whole, rather than to focus on assessment in isolation. Effective learning is more likely when students are given, and accept, responsibility for their own learning and have some control over the learning context. Widespread use of formal lectures do not make this possible, but small group work, if structured to enable cooperative learning, can enable student autonomy [see, for example, 27, 28]. Such work is associated with the use of deep approaches and high quality learning outcomes [10].

Problem-based learning

One example of this type of work is problem-based learning, where a group of students work collaboratively to solve a particular problem [29, 30]. The problem, which may be interdisciplinary, drives the curriculum; students must define the problem, identify and acquire the skills and knowledge needed to solve it, and work through the solution. Students are required to take responsibility for their own and the group's learning, and hence are both autonomous and independent. Learning is self-paced and takes place in the context of a realistic problem, the manner of working being close to that of engineers in industry. Engineers see themselves as problem-solvers, so the learning context is seen by students as being relevant. In addition, students gain experience in the integration and application of analytical knowledge. All of these features mean that problem-based learning encourages the use of deep approaches to learning [10].

One of the most radical implementations of this form of learning is seen at the University of Aalborg in Denmark, where the curriculum is entirely problem-based. Engineering students work in groups on interdisciplinary, design-oriented projects, which are supported by lectures, reading, group discussion, tutorials and practical exercises as appropriate. The first year of the undergraduate course is common to engineering and science, and contains projects which enable

students to acquire group skills as well as subject-related knowledge and skills. This year is followed by two specialised years in engineering.

The Aalborg degree has been evaluated in comparison with a traditional engineering course at the Technical University of Denmark in Copenhagen [31]. The results showed no difference in quality or level between graduates of the two universities, but graduates of Aalborg were 'stronger in problem-solving, communication, cooperation and general technical knowledge' while graduates of the Technical University were stronger in 'specialised knowledge and technical methodology' [31]. The weakness in specialised knowledge has been noted by Aalborg and steps are being taken to correct this by introducing more general courses [32].

At present, a problem-based approach is used in some design courses in conventional engineering degree programs; however this is not true problem-based learning as the emphasis is on integrating engineering science material previously taught in other courses, rather than on learning new material. However, problem-based modules have been introduced into analytical courses in a number of conventional degree programs. Cawley [33] for instance, converted a conventional final-year vibration course to a problem-based format, because he was concerned that the existing course had too great an emphasis on technical theory and too little on the application of theory to real problems. Problem-based approaches have also been used in a number of courses in the Department of Civil Engineering at Monash University, inspired by a desire to actively engage students in their learning [34, 35].

In another example, Woods [36] combined the problem-based approach with self-directed learning in a third-year chemical engineering economics class, to overcome the problem of how to facilitate small group work in a class of 45 students with only one staff member. Students first attended a total of 80 hours of workshops over five weeks on process skills, then were formed into groups of five. Each group was given a problem, required to identify the content needed, teach the content to each other and then use it to solve the problem. Woods [36] reports a high degree of enthusiasm and active learning on the part of the students, although some students (about 20%) were unwilling to take charge of their own learning.

Assessment is another factor which must be taken into account when implementing a problem-based module. Assessment needs to be carefully designed so that it does not counteract the aims of the rest of the course. For instance, Drinan [37] warns that, unless assessment requires students to demonstrate understanding and integration of knowledge, they may 'guess their way from problem to solution without seriously engaging either sources of information or mental facilities'. Ideally, a wide range of assessment methods, which test understanding and which are embedded in the

course rather than added on at the end, would be used [38]. For example, self- and peer-assessment in addition to assessment by academic staff can reinforce the concept of students as independent learners, and readers are referred to Biggs [39] and Brown and Glasner [40] for a full discussion of these and other methods.

CONCLUSIONS

Changing needs of employers, away from specialisation and towards flexibility and lifelong learning, together with a student intake less prepared than in the past for tertiary-level study, make a case for change in engineering education. However, change needs to be built upon a sound understanding of the factors that affect student learning. This paper has shown that three such factors are involved, namely conceptions of learning, approaches to learning and the learning context. Various aspects of the context set by traditional methods of teaching engineering,

discourage the use of deep learning approaches which can lead to high quality learning. This occurs largely because the present context fosters passivity and dependence, and a view that learning is external to the student.

One approach which forces students to take responsibility for their learning, and thus ensures deep and active involvement, is problem-based learning. Although this can be used to structure an entire engineering curriculum, a more practical approach with existing courses is to combine an increase in the amount of problem-based work with a decrease in workload. In addition, assessment must focus on testing understanding, rather than memorising and reproducing. Such changes have the potential to greatly increase the effectiveness of present engineering education.

Further reading—Good starting points for readers wishing more information about the general teaching and learning issues discussed in this paper are the books by Ramsden [10], Biggs [39] and Prosser and Trigwell [41]. For specific information about problem-based learning and its implementation in a range of educational fields, see Boud [29, 30]

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