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Teaching Engineering Design Through Project Management

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This paper describes the parameters affecting the teaching of design as part of existing educational and training programmes for engineers at the third level. It is established that there is little substantive design input to be found in these programmes and that there are severe restrictions on the introduction of additional material. This is due both to the nature of the design activity and to external constraints imposed on the curriculum. This paper examines the origin of the major difficulties with teaching design, and then describes an innovative project-based course that can be accommodated within existing curricula.

INTRODUCTION

IT IS frequently acknowledged [1, 2] that there is little substantive design input in the educational and training courses of engineers in third-level institutions. In Ireland, as in many other countries, full undergraduate degree courses are run under severe manpower constraints, both teaching and technical—a situation that more often than not leads to conveyor-belt teaching methods and single end-of-term examinations. And since many teachers in these institutions have little or no professional experience outside academia these teaching methods are seen as adequate—and even preferred. In this environment, studying design is seen simply as studying another subject heading, rather than what it is: a highly conceptual and participatory activity that requires exposure to a wide variety of material and thought processes.

The structure of engineering degree programmes throughout the world is largely predictable and similar; even where they differ, they are converging. Indeed, the comparability and similarity of syllabi is perceived as a factor which contributes to a successful outcome of the professional accreditation process. This process, it is suggested [2], ensures that engineering educational standards will be maintained and worldwide reciprocal recognition of those standards will be realised through appropriate national bodies. This, in turn, will guarantee an acceptable and recognisable level of education within the engineering profession. The organisation of the medical profession is often selected as a comparative model to emulate.

Whilst there are many laudable arguments to support this general view, there are also dangers. It must never be forgotten that professional bodies only specify minimum academic standards. Furthermore, they do not generally specify how these standards are to be attained (although in engineering it is usual to have theoretical subjects assessed through a formal examination process complemented by a series of laboratory-based practicals and/or project work). Some of the more 'progressive' degree programmes often require a period of work experience which, whilst compulsory, is not usually part of the assessment process.

Any degree programme (or single course) that does not conform to this model is quickly identified as requiring special attention—simply because it is different. By implication, and indeed in practice, a programme that conforms to the standard format is given a comparatively less thorough review. The standard, then, gradually becomes one of conformity rather than one of excellence. The immediate and obvious casualties of this process are innovation, thinking and design.

A brief illustration is given below, of the static and hierarchical structure of a fairly typical undergraduate curriculum in engineering from which it is possible to identify the major parameters affecting the introduction of (more) design into the existing structure. This is followed, in the section on Project Management, by a definition of design which is then used as the basis for a brief discussion of the nature of the activity of design. The conclusion presents a description of the content and methodology of a compulsory design course introduced to Industrial Engineering students in their penultimate year of study at University College, Galway.

THE CURRICULUM

Present structures

Whenever there are discussions or recommendations that involve change, there is always a strong lobby to maintain the status quo. And nowhere is

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the resistance to change more hard-fought than when the topic is teaching curricula. At universities, where teaching staff have a large degree of independence in regard to course content and structure, one might expect a high degree of innovation. But this is simply not the case. Any changes that do come about are usually the result of a gradual percolation of material from higher-level courses down through the hierarchical teaching structure. Additional external demands of professional accreditation bodies simply add a further layer of resistance to change.

Table 1 presents an abbreviated extract from a university calendar which lists some fairly typical subject headings of the first two years of a four-year undergraduate degree course in engineering (Electronic Engineering, in this case). The partitioned structure of the curriculum is clearly in evidence, as is the predictability of the content to any engineering educationalist. The assessment of each subject is generally by written examination. Practical and/or skill-based subjects usually contain laboratory sessions of the conveyor-belt type: alphabetically-assigned groups of students repeat the experiments, drawings and computer assignments carried out by generations of predecessors. Students quickly recognise the sheer tedium and irrelevance of the teaching and assessment methodology and soon learn to devote their energies to mimicking the highest scoring products of past students. Furthermore, the participative or practical element rarely counts for more than 20% of the overall assessment in any year. A fuller account of this type of degree programme is given in reference [3].

To compound matters, the supervision and assessment of practical work in the form of laboratory reports and assignments is a relatively time-consuming activity. As a consequence, it is often delegated to graduate students who, more than likely, underwent the same tedium only one or two years previously. That such a situation continues to regenerate itself on an annual basis is adequate testimony to the inertia of those institutions involved and, indeed, of the accreditation bodies.

Quite often, though not always, students undertake a definable project in their final year which tends to boost the participative element (in that year) to somewhere in the region of 30% of the overall assessment. In regard to the activity of design, the overall picture is much worse: since the project-based activities occupy only 30% of the overall assessment then, at best, this is the maximum proportion that can be identified with design. Normally, however, the design element is but a small fraction of these project-based activities.

As already stated, one of the main obstacles to the introduction of design into an undergraduate teaching programme is that the curriculum is seen, overall, as fixed and compartmentalised. This perception illustrates the generally held but unstated view that knowledge can be bundled under separately identifiable headings, i.e. it illustrates a false epistemology [4]. As a consequence, any suggestion that design (or more design) be introduced into the curriculum is reduced almost immediately to a question of which other course(s) it might replace. In this intellectual environment, design is perceived simply as another subject heading rather than a synthesising activity. Moreover, the introduction of any additional continuous assessment/assignment-based material is seen to demand too much time commitment—particularly from academics who can find hope of promotion through competency in research or committee work but not through teaching.

The learning process

Although there are several conflicting theories on the psychology of learning [5] there is general agreement that knowledge and understanding are acquired much more effectively if the subject matter under study has some direct relevance to the student [6]. This relevance may take almost any form: an affinity with the teacher, an overlap with a hobby, or a keen interest in intellectual activities.

This factor is recognised in the more enlightened degree programmes by the inclusion of projects as part of the syllabus, as noted above. Further, some programmes require students to gain outside experience in the form of summer work in appropriate engineering companies or by working full-time for a company for several months. The

Table 1. The first two years of an undergraduate curriculum (source: Calendar 1990/91, University College, Galway)

Year 1		Year 2
Mathematics	---->	Mathematics
Mathematical Physics	---->	Mathematical Physics
Experimental Physics	---->	Experimental Physics
Chemistry		Strength of Materials
Computer programming	---->	Numerical Analysis
Engineering Drawing		Electrical Circuits
Years Work		Hydraulics
		Electronics
		Years Work

positive effects of these activities is well known and only inertia prevents further developments in these areas. Other approaches involve the development of enhanced degree courses and of extended degree courses [2]. Whilst there are many reasons for these approaches, one very fundamental element is always present: the experience gained in these activities allows the student to develop a more mature attitude towards university studies, i.e. he/she gains in confidence and experience and begins to develop some perspective regarding the relevance of course-content. Normally, this provides a spur to learning, particularly if the experience is also seen to have a fun element or produce a personal sense of achievement.

Design

Despite the volumes already written about 'design' there remains a persistent confusion regarding its meaning which is best illustrated by attempts to derive a definition [7, 8]. One such definition of design is worth repeating [9]:

> That area of human experience, skill and knowledge that reflects man's concern with the appreciation and adaption of his surroundings in the light of his material and spiritual needs. It particularly relates to the configuration, composition, meaning, value and purpose in man-made phenomena and his concern with providing an optimal solution to such needs in terms of fit, form and function (it is analogous with Humanities and Science).

Almost every word within this definition simply layers confusion upon confusion. Does human experience exclude skill and knowledge? What does *appreciation* mean in this context? What do material and spiritual needs signify? In what context is *optimal* defined? And what implications is anyone supposed to extract from the last qualifier in brackets? Furthermore, in the context of this paper, how can anyone with such a notion of design attempt to teach it?

In common with many other alternative definitions, the one above underscores conceptual errors that arise when words are divorced from a rationally-based philosophy. These conceptual errors are a direct result of the compartmentalisation of knowledge. At its most general, an acceptable definition of design must be one which encompasses all known meanings and nuances, can be validated by experience, and is concise. Such a definition must, at its root, be philosophical in context since it is only at this deep conceptual level that the full implications may be realised. In other words, such a definition must rest on solid epistemological and metaphysical foundations [10].

It is probably instructive to produce a definition of design and then proceed with an evaluation of its accuracy. For the sake of discussion, it is easier to start with the noun:

> A design is a man-made product or process that satisfies acknowledged and stated criteria.

This definition states concisely that a design may be either a product (artefact) or a process (method) that is the end-result of man's purposeful activity. Note that inanimate objects, plants or animals are deliberately excluded since only man is able to engage in the activity of design. Further, that the design activity is purposeful, is made explicit by stating that the *characteristics* of the end-result are prescribed by the initial starting criteria—such criteria having been acknowledged (accepted) and stated (recorded) at the outset *by the designer*.

In this definition—and in reality—it is immaterial that the initial design specifications may have been compiled by the boss, established by market research or produced from market push. The crucial point is that the designer must have acknowledged such specifications *before* commencing work. It is important to stress that the initial design criteria must be stated, since the only alternative is to have *unstated* criteria. And finally, it should be noted that the word *criteria* is used in its full context—as a standard of judgement, i.e. it includes both constraint *and* purpose.

The verb may now be dealt with more readily since a definition follows directly:

> Design is any purposeful means of realizing a stated objective.

This definition is, quite deliberately, made dependent on the conceptual content of the noun. And although such a definition cannot stand alone, the full meaning is quite clear. In addition, the details (in this case of the design process or methodology) have been omitted in order to provide a general context. The word *any* could easily be replaced by *the* but has been included to emphasise the point that the activity of design is objective orientated, i.e. the precise methodology depends entirely on the desired end-result. And finally, two additional points are worth repeating: (a) the design activity is a *purposeful*, i.e. human activity, and (b) the end-result of the activity is *realised*, i.e. exists in reality.

Perhaps a combination of the two definitions is preferred:

> *Design is the purposeful means and the end-result of realizing a product or process that satisfies acknowledged and stated criteria.*

Summary

From the foregoing observations and discussion it is possible to make some general comments on the introduction of (more) design into an undergraduate engineering curriculum:

- There is a general lack of understanding about the nature of design which is compounded by a false perception of the structure of knowledge.
- To teach design effectively, it must be introduced as a project-based activity and continuously assessed; the student must be allowed to develop through a regular and meaningful feedback mechanism.

- Design projects must be seen to be challenging and as far as possible, fun. Neither teacher nor student will gain anything if the same projects are repeated, year after year.
- The activity of design should be presented through as wide a range of material as possible. Design projects which involve their everyday surroundings will encourage students to learn that the activity of design extends beyond the classroom.

PROJECT MANAGEMENT

Following the evaluation of the effectiveness of several pilot and partial programmes spread over a number of years, a single continuously-assessed project-based course on design was introduced in October 1989 to Industrial Engineering students at University College, Galway in their penultimate year of study. In a design context, one of the attractive elements of the Industrial Engineering course is that it covers a much wider range of material than more traditional engineering courses. It should be added that this design course has been established within a degree programme completely dominated by courses of the traditional format.

Course format

During a first introductory lecture, students are informed that the course differs from other more conventional courses in three important and fundamental ways:

- the teaching methodology involves occasional specialist lectures rather than the usual two hours per week;
- the overall assessment is continuous rather than by a single end-of-term examination;
- student participation is active rather than passive.

Additionally, the course demands the widespread use of computing facilities, not just as an end in themselves but as part of the overall professional training. The assessment methodology also demands the submission of typewritten reports at the end of each project. Much to their surprise they receive their first assignment at the end of the first lecture.

As a follow-on, during the second week, the author's view of design is outlined briefly. The role of problem-solving, inquisitiveness and thoroughness in preparation, planning and presentation are highlighted. This second lecture ends with the specification of a second assignment which is intended to get students to synthesise concepts and broaden their terms of reference. Examples of topics for these early assignments are: 'What is design?' 'What role has a university?', 'What is a professional engineer?'.

During the third week, the class is allowed to split into four groups of approximately equal size, i.e. about ten per group. This is normally the first time they have ever been allowed to exercise a choice in the matter of their co-workers, since it is a common practice amongst teachers to lump students together from an alphabetical list of the class. These relatively large groups are allowed to choose from a short list of projects such as waste recycling, parking and traffic problems on and off campus, sick building syndrome, pedestrianisation, and student timetables. Since one of the primary objectives of the course is to encourage students to identify problems and propose solutions, the groups are generally left to organise themselves according to their collective abilities, interests and inclinations. Some groups splinter into smaller factions and others remain as a fairly cohesive whole. During this period, the class are introduced to word processing and document preparation, and assessment is based on individual project reports and interviews. Also during this period, students are exposed to a complementary and continuously assessed Project Reporting course.

As these projects come to an end students have, for the most part, already formed self-determined subgroups which are then asked to select their next project from a prepared list or to suggest projects of their own. From this latter option there have emerged two excellent project reports: the first on the problem of bird strikes for aircraft, the second on an automated football management system for secondary schools. Usually, however, a choice is made from the prepared list; each group consisting of two to four individuals. These projects cover a wide range of material and demand the acquisition of new knowledge, techniques and skills appropriate to the scope and depth of the project itself. For example, areas covered include the design of a car refrigerator, the design of a self-powered road sign, the design of a boat trailer, the design of a satellite dish, computer control of analog devices (in robotics, NC machining and experimentation, for example), the design of experiments and database development. Over the remainder of the academic year students may undertake up to three to four projects—all of which are assessed on the basis of written reports and, if appropriate, oral presentations.

Course director

From a teaching viewpoint, all projects are managed and directed through regular meetings with each group. This is very time-consuming, as is the assessment of reports. There is also a heavy demand for the provision of both computing and laboratory facilities. In other words, this type of course demands a much greater intellectual, resource and time commitment from the teacher than other conventional courses. On the positive side, the teacher can see first-hand that students are both learning and, by and large, enjoying the process. And since projects may continue from one year to another, larger tasks can be progressed sequentially over a period of time.

CONCLUSIONS

Fundamental philosophical errors have been identified as the root cause of a widespread misunderstanding of the structure of knowledge. These errors have led to engineering degree programmes characterised by compartmentalised, fixed and hierarchical subject structures. In such an environment, the essential synthesising activity of design is either neglected or suppressed. The inertia of educational establishments to change is compounded by the demand of accreditation bodies that degree programmes conform to the same form of hierarchical structure.

A single continuously-assessed course on design has been introduced within an engineering curriculum dominated by conventional teaching and examination methods. This course more than satisfies the minimum standards set by accreditation bodies. Despite the short period that this course has been running, the consequences are already becoming noticeable: a significant increase in the demand for computer facilities, the development of laboratory and classroom facilities and, indeed, a complete review of the undergraduate curriculum has begun within the Department and some changes initiated in first and second years. Not least, undergraduate students are involved in many diverse subject areas which are seen to progress from year to year. A limited intake optional course on design was introduced in October 1990 to final-year students organised on a similar format, and a graduate course on design commenced in October 1992.

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