REFLECTIONS FROM THE EDGE: ENGINEERING EDUCATION VIEWED THROUGH A DIFFERENT LENS

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ABSTRACT

Disciplinary approaches are a product of our learning within a discipline, the paradigm of practice created and accepted by any given discipline. The generation of knowledge within a given discipline is governed by the cognitive and social norms which must be followed in the production, legitimisation and diffusion of knowledge. Our interaction with engineering education is significant and consequently we are able to offer this alternate 'lens' via our own 'different' discipline training. We hope this paper provides new insights and a catalyst for engineering discipline trained educators to understand what their practice looks like from the outside in!

INTRODUCTION

Yvonne Toft, a professional with extensive industry and university experience specialises in human factors design and systems safety. Her research over the last decade has centred on informing changes in the professional practice paradigm of ergonomics and engineering, towards the development of collaborative, ethical and informed design development to improve the safety and productivity of systems. Although Yvonne's primary teaching area relates to occupational health and safety (OHS), she teaches design related topics to undergraduate engineers across all year levels and has won curriculum innovation awards for this work.

As a practitioner and academic, Patrick Keleher, with applied physics, mathematics and computing and educational qualifications has extensive experience as a developer and deliverer of diverse curriculum for these three disciplines and also engineering curriculum. The combination of physics and mathematics as fundamental keystone disciplines of the engineering discipline and an educational background, focussing upon a wide range of learning and teaching styles and delivery media has equipped him well to engage, support, guide and provide leadership in developing engineering educational resources and in training people with engineering backgrounds at both undergraduate and postgraduate level. The grounding in fundamental and applied physics and with a doctoral degree in control theory affords him the ability to operate within the individual disciplines of physics, mathematics, civil, electrical and mechanical engineering and also to operate within a multi-discipline or trans-disciplinary approach.

WHAT DEFINES A DISCIPLINE?

'Disciplinary' approaches are a product of our learning; the paradigm of practice created and accepted by any given discipline. Discipline knowledge is governed by cognitive and social norms resulting from the production, legitimisation and diffusion of knowledge. It is the training in a particular disciplinary language, knowledge generation disseminated through particular peer review publications, socialisation in the 'norms' of that discipline through professional association. 'Disciplinary knowledge', purports Nicolescu(9), is produced *in vitro*, is objective, leads to knowing, is the result of analytic intelligence, has an orientation towards power and possession, follows binary logic and excludes values.

PHYSICS AS A DISCIPLINE

Physics derives from the Greek, *physikos*, meaning 'natural'. It is relates to the study of the fundamental constituents of the universe, the forces they exert on one another, the outcomes from such interactions and the exploration and explanation of a wide range of physical phenomena spanning the microscopic and macroscopic. Some of the phenomena studied in physics, for instance the conservation of energy, are common to all material systems and are referred to as the laws of physics. Physics is described as being the 'fundamental science' because other natural sciences (biology, chemistry, geology, etc.) deal with particular types of material systems obeying the laws of physics.

ERGONOMICS AS A DISCIPLINE

Ergonomics (or human factors) is 'the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well being and overall system performance' (International Ergonomics Society[7]). The word 'ergonomics' is derived from the Greek, *ergon*, meaning 'work' and *nomos*, meaning 'laws' and in the broadest sense denotes the science of work. Ergonomics is a systems-oriented discipline.

ENGINEERING AS A DISCIPLINE

Arguably, rocket engineer, Theodore von Karman(17), defined, perhaps, the most widely quoted and understood definition of engineering as a discipline, 'science studies what is; engineering creates what never was . . .' While Wulf(19) outlines an operational definition:

'We design solutions to problems. However, there are a set of constraints that we have to satisfy – size, weight, reliability, safety, economic factors, environmental impact, manufacturability, reliability, and a whole list of "—bilities". Engineering is not "just applied science". It is an entirely different way of thinking. It is a profoundly creative discipline . . . in my experience, science (our knowledge of nature) is one of the constraints that we work under, but it is seldom the most stringent constraint, or the hardest one to satisfy.'

LIVING ON THE OUTER EDGES: PHYSICISTS

Syndergaard(15) in criticising Rigden(14), contended:

'No other magazine I receive spends so much time in self-pity or self-hype as this. Get a clue. It really does not matter what your job title says as long as you do something you like to do and you are receiving fair compensation',

while Rigden(11) retorts,

'Responsible industry people know what an engineer is and what engineers do. This is definitely not the case with physicists . . . physicists are immediately given a *nom de plume* in company records, and then it is forgotten that these valued employees have bachelor's degrees in physics'.

Rigden(11) and the responses evident epitomise the feeling of distance, lack of understanding, deficit of fundamental knowledge about and undervaluing of physics as a discipline. It also demonstrates the obstacles the discipline faces when engaging in; physicist-engineering, -industry, -government and -society relationships. When seeking to have 'physicist' acknowledged in their job title Lipkin(8) explains 'general opinion had me as being slightly eccentric for even caring to make the distinction'. An engineer, Chaiken(2), advised 'don't hide the fact that you're a physicist, but don't blurt it out and emphasize it so as to scare people'. Farr(5), as a physicist, has 'forgotten how many times . . . personnel officers explain they "only hired engineers" '. Fleck(6) explains he has had numerous people ask why he went into physics, since 'there are almost no jobs out there' and that he had corrected them by saying that physicists were pivotal in that 'in numerous situations people actually employ physicists before anyone else because they tend to pick up on things faster and can bring new ideas into the workplace'. However D'Souza(4) contends marketing is a major issue for consideration, explaining 'physicists don't market themselves effectively'. Synnes(16) agrees and highlights 'physics degrees, when properly marketed, will open many technical employment doors'. In the industry, government, society and engineering relationship spheres D'Souza(4) emphasises the issue lies with physicists, as they may be 'naïve about the expectations and requirements of industry' and that from the industry perspective 'applications often are screened by personnel who are not knowledgeable about the difference between physicists and engineers' and in the arena of interacting with engineers, society and management he argues that 'while physicists view engineering as applied physics, the general public, and many engineers and managers, do not make this connection'.

In 'living on the outer edges', as Rigden(11) emphasises; Result 1: job titles become the reality. Result 2: when a new physicist looks for employment, the response can be, 'We don't employ physicists'. Wagner(18) states a *prima facie* case when he emphasises that 'job titles and job descriptions reflect what people do, their level of responsibility, and their years of experience'. Being out on the 'edge' without a 'name' anyone would acknowledge the difficulty to be an advocate for something that government, industry, society and engineers cannot even describe. The ramifications are telling. Perception leads to reality and thus the consequential devastating impact and lack of understanding, support and recognition is articulated in the question being placed on status as a profession and the importance of the discipline's body of knowledge, its relevance to society, industry and government, adding to the difficulty to attract young people to take up physics at secondary and tertiary level and the provision of funding and career opportunities (study, academic arena, research). Being thought that you might 'scare people' or thinking that you may be seen as being 'slightly eccentric' for wishing to be acknowledged for what you are or what your discipline stands for is symptomatic and ultimately it would be more comforting to be 'recognized as what we are rather than our aliases' (Register[10]). A case of - 'What's in a name? That which we call a rose by any other name would smell as sweet' (Shakespeare[14]). And so it is, but it is whether or not you value 'roses' (physics and physicists).

Wagner(18) responds to Rigden(11) highlighting the skills and knowledge that physicists possess equates to a 'knowledge of basic physics principles', 'have highly developed problem solving skills', have the 'ability to synthesize concepts from seemingly disparate pieces of information,' can 'pick up on things faster', 'bring new ideas into the workplace' and this results in 'a more fundamental understanding of the possibilities of solutions'. Wagner(18) concludes it is 'not whether physicists are better, but that they are different' and they 'approach applied challenges differently than do engineers and others. From this perspective, physicists provide an especially important asset in multidisciplinary teams'.

While Rigden's(11) article appeared over eight years ago the same dilemmas abound. From a personal perspective and based upon physics qualified colleague's testimony, the same challenges of inertia, lack of understanding and appreciation of one's capabilities exists when attempting to engage with industry for employment (as individuals and for students (work placement during their study, graduates), seeking funding for development of courses and programs relating to physics or having a purely physics focus, and when offering expertise for consultancy and research projects. There is a constant need to substantiate and to validate one's credibility as a disciplinary and knowledge provider or capable professional in technical and educational fields continue.

LIVING ON THE OUTER EDGES: ERGONOMISTS (OR HUMAN FACTORS ENGINEERS)

In accepting the International Ergonomics Association's definition, 'ergonomics' and 'human factors', become interchangeable terms. Thus it is easy to see why the profession seems to have an identity crisis.

In Australia, the dominance of physical ergonomics means the term 'ergonomics' is understood as relating to physical factors; manual tasks, ergonomic seating, computer workstations. 'Human factors' is emerging as the preferred term to explain relationships between workers and systems; issues related to latent sources of error, evaluating information processing requirements and informing interface design. Recent communications from the coal mining industry consistently refer to 'human factors' as a term to describe an enriched process of finding the system/design failures that trigger operator error. Byrne and Gray(1) assert Human Factors as a discipline, should return to the engineering fold, explaining:

'Human factors is a disparate discipline. Academic programs in human factors are found in departments of industrial engineering, psychology, mechanical engineering, architecture, optometry, and elsewhere. Human factors professionals are employed in a variety of industries, at many levels in the organization chart, and hold an equally disparate array of job titles. However, many hold job titles along the lines of "human factors engineer," and many academic programs housed outside engineering departments still refer to an engineering component . . . for instance, many human factors programs in psychology departments are termed *engineering psychology*. Thus, despite the fact that the field is far from uniform or unitary, there is clearly a strong engineering presence. Is this merely a label or is this how human factors is actually practiced?'

They argue strongly that to claim something is engineered is the application of mathematical and natural sciences and that these have been put aside as the nature of human factors problems (driven by advances in technology) have changed; using the cockpit of modern airlines (Byrne and Gray[1]) demonstrates that:

'. . . this change in the character of many essential human factors problems has naturally given rise to a change in methodology and terminology. Even the best, most quantitatively accurate manual control model does not scale up to issues of crew coordination and training. However, this change has de-emphasized, at least to some extent, the use of methods and practices found in mathematics and natural sciences, a "deengineering" of the field. Although this was probably necessary to scale up to modern human factors problems and issues, we believe the advancement of quantitative practices is critical to the continued development of human factors as an engineering discipline . . . we believe there is a new movement toward the development of engineering style approaches appropriate for problems in human factors. This movement has been centered on quantitative models, which play a key role in modern engineering practice . . .'

THE DISCIPLINES: ENGINEERING, ERGONOMICS AND PHYSICS

Interestingly, in particular to the physicist-engineer dynamic, is that in most universities prospective physicists and engineers study in the same classes and are instructed in the same manner. Why? Students at secondary school, whether they become engineers or not, study physics not engineering as a recognised discipline. Why? In some instances the tradition of education as a socio-economic aspect overseen by governments is the reason. Perhaps this highlights the recognition and importance that engineers, society, industry and government place on the fundamental principles of physics or did. Does this imply an inherent connection between the two? Which exhumes which? - does it matter? - is physics the cornerstone and engineering merely a 'technical' sideline, seen as being less than, of applications of central themes and fundamental knowledge (natural truths and laws) but the 'real' knowledge is physics?

Are engineering and physics Siamese twins or Jekyll and Hyde? From the previous discussion the serious aspect remains - if engineering is a discipline distinct from physics why then has physics such a central role in engineering and engineering education? From a personal perspective, in designing, teaching and implementing physics courses or physics-related courses, for engineers to undertake in their undergraduate degree, the learning and application of physics principles are relegated to a functionality rather than a 'serious', more holistic endeavour to understand and apply any real knowledge. Physics is considered, like math-ematics, so that the engineering academics seeking the course development and indeed the students have the mindset which can best be described as 'just show me the bits I can use as a tool, I don't need to know the fundamental or theoretical foundations or why it works just how I can make it work to get the answer'. In this manner they are shallow learners of physics and mathematics and so if the fundamental physical or mathematical conditions alter then no matter how much application of the little knowledge they have will yield the correct answer and no amount of credible engineering will occur.

Robinson(13) helps explain how engineers sees the disciplines of physics and mathematics as mere tools and not the fundamental elements for reasoning or solving any engineering problem in that 'engineering solves problems using physical science and mathematics. Its links to those disciplines are clear. Yet, in terms of engineering thinking and rhetoric, its dependence on them is really accidental rather than essential'. Indeed Robinson(13) believes 'engineering's goal (problem solving) and its method (deduction and analogy) is much closer to medicine and ethics than to science. Its rhetoric (justifying its analogies) is close to law, and perhaps to economics'. The crunch: In such circumstances as described previously to solve a problem they encounter they do not seek out the legal, medical or finance professions nor an ethicist to provide them with the deeper knowledge required. Instead they seek out a physicist or a mathematician to help them solve the problem. All the while never acknowledging deeper learning of the physics and mathematics principles would have equipped them better as a profession.

Ergonomics challenges this also as Daniellou(3) examines underlying assumptions underpinning ergonomic practice. Ergonomists, or Human Factors Engineers, emerge from a variety of professional areas with the professional domain predominately a postgraduate area of study. The undergraduate areas that feed into ergonomics as a specialisation include many professional practice paradigms, for example, engineering, management, psychology, human movement and health sciences. This diversity within the professional membership base perhaps provides the greatest challenge to ergonomics being distinguished as a single discipline (yet in some ways is reflective of modern engineering).

Daniellou(3) proffered the epistemological issues ergonomists need to address that are not normally in issue in the practice of one single discipline:

- 'ergonomics deals with technical devices and human beings in systems where the 'laws' are of different natures;
- it is orientated towards action in real situations;
- it takes on both health and efficiency issues;
- it deals with social situations which raise all the questions of liberty and power struggle;
- it deals with complex systems characterized by non-linear answers, uncertainty about the initial state, variations in the context and the number of influencing factors;
- as a design discipline, it has to do with 'things that do not yet exist', the existence of which is both a matter of technical feasibility and political will;
- it is continuously facing ethical dilemmas . . . and;
- one of the ways it uses to produce knowledge about the phenomena is by changing them (knowledge through action).'

This seemingly diverse paradigm of practice is actually the essence of ergonomics and defines it as a discipline. The essence of ergonomics is the holistic application of systems thinking, a seamless integration of physical, cognitive and organisational aspects to improve (or optimise) the interaction between humans and other elements of the system. Ergonomics is a 'way of thinking and problem solving'. 'Engineering is *not* "just applied science". It is an entirely different way of thinking. It is a profoundly creative discipline . . .' (Wulf[19]). Is engineering the inclusive middle with ergonomics at one edge and physics at the other?

While we would describe science as a discipline and express comfort with that, engineers, from our experience, appear to be emphatic when referring to civil, electrical, mechanical, chemical engineering, etc. as disciplines and that 'engineering' is just a category or a collective title for these disciplines. They do not appear to be comfortable with what they feel is an umbrella term, 'engineering', to be defined as a discipline.

From observation scientists (chemists, biologists, ergonomics or physics) appear to deem it natural or are at least more comfortable working within multidiscipline or trans-disciplinary teams. Any science graduate that completes their degree is immersed in an academic culture which encourages them to study for a higher degree in their discipline or outside their discipline. The completion of their undergraduate degree is seen as a starting point. For an engineer the completion of their undergraduate degree appears to be a termination point; a type of 'I have studied to be an electrical engineer and when I graduate I will be an electrical engineer for the rest of my life no matter what' perspective. In this way they are what we would term 'discipline introverts'. As Postgraduate Director, Patrick Keleher observes even when an engineer completes postgraduate qualifications in Maintenance Management, invariably when asked what their profession is, reply, describing their primary engineering qualification, 'I am a mechanical engineer' or 'my background is in civil engineering'.

Wulf(19) emphasises an urgency of change in engineering education, nominating educators of such discipline, rely upon such creativity, should be required to express that creativity, that is, have practised as an engineer and that many engineering educators would not meet this criterion. They would understand the real context of engineering if they had. This is our experience as well; enlightened engineering educators are very creative and require only being challenged to such new possibilities to gain wonderful results. The 'potentially' that is inherent in the field of engineering education is limited only by this ability (or not) to see the world through a new lens.

CONCLUSION

This has not been a discussion about which discipline is better or which is the most clever. We highlight a lack of acknowledgement for the fundamental roles that are apparent when disciplines interact. It is the intertwining and understanding that dependencies can and do exist. It is about mindsets and perceptions and about creation of knowledge and the solution of problems by a joint effort of the constituent contributors. It is about blurring the edges and about defining and celebrating the distinctions.

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ADDRESSING CHANGE IN UNIVERSITY DEPARTMENTS: A STRATEGY OF DISCIPLINE-BASED SUPPORT

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ABSTRACT

The UK Centre for Materials Education (UKCME) is one of 24 Subject Centres which form part of the Higher Education Academy, providing discipline-based support to universities and communities of practitioners from across the UK. Throughout, its work has been subject to external evaluation, and this paper draws on evidence relating to this. It considers both the barriers operating, and the approaches adopted by the Centre to promote implementation of teaching developments.

The paper argues, that the Centre has enjoyed considerable success because it has shown awareness of issues relating to change, and has attempted to develop strategies accordingly. It is now evolving practice to address institutional barriers by engaging more actively with the 'real engine' for change, the university Department, through the new initiative of a 'Supported Change Programme'.

INTRODUCTION

In its recently produced Portfolio of Activities, the UK Centre for Materials Education (UKCME) identified its aims as:

Supporting high quality student learning in Materials and related disciplines; promoting, encouraging and coordinating development and adoption of effective practices in learning, teaching and assessment.

In describing its activities to-date, the UKCME adopted a knowledge pathway model, the role of the Centre being to enhance student learning by 'creating and promoting pathways of all kinds' which would 'connect those seeking knowledge relating to teaching/ learning with someone who could help develop that knowledge'.

Inevitably, it has been the Centre itself which has operated as the major provider of knowledge, through workshops and seminars, and by making a range of resources available to colleagues. However, the work of the Centre has been characterised by much more than a simple transmission model of knowledge. Other approaches have been adopted and all of these externally evaluated. This process of evaluation, and the thinking underpinning it, is considered in greater detail below.

MESSAGES FROM EVALUATION

The UKCME has not developed its practices in a vacuum, but has responded to messages from external evaluations.

The early phase of external evaluations set out to ascertain what had been the initial impact of the Centre's activities, focusing in particular on workshops. A series of evaluation reports documented participants' perceptions, and revealed that initial response had been very positive. The evaluation has not, however, been confined to a detailed scrutiny of activities. Another strand was added to explore both the educational philosophy underpinning the Centre, and of the methodology adopted to promote change. This identified priorities and delineated strategies. In this way, evaluation went beyond a focus on what the Centre does to consider the 'why' and 'how'. The evidence for this strand was collected from attendance at meetings and through interviews – both formal and informal – held with team members at the Centre.

Evaluation has since moved on. There is now clearer appreciation of what the Centre is trying to do and why. The initial very positive impact of its events has been well documented. But, has the Centre had any lasting effect? Has anything really changed? Attempts have been made to find answers to these questions.

Questionnaires have been circulated to colleagues in the Materials community in 54 targeted institutions. Complementary in-depth semi-structured interviews have also been held with 21 colleagues in 10 higher education institutions. This research of the Materials community, (Taylor[1]; Taylor and Ball[2]), clearly revealed that there are limits to what can be achieved through the presentation of workshops/seminars and the production of resources – stimulating as they may be in the short-term. Barriers to change may exist beyond the control of the Centre.

A further insight into this can be gained from a more recent study in which questionnaires were completed by 41 participants at regional workshops organised by the Centre. The sample was drawn equally from pre-1992 universities and ex-polytechnics. The majority (32 of the 41) regarded themselves as experienced lecturers. Most (30 of the 41) were teaching Materials as part of a broader engineering programme. This study focused primarily on barriers to change, and captured a mix of statistical and qualitative evidence. Participants were asked to consider a series of potential barriers, and to indicate the extent each operated to limit their capacity to develop their teaching.

From the study, three major factors have emerged which prove to be strong barriers to promoting educational development in the Department. These are summarised in **figure 1**. The first factor relates to the culture of the respondent's workplace – for instance, a focus on teaching will limit a colleague's potential prospects. The other two factors take us closer to the day-to-day reality of the workplace – for instance, other issues are regarded as important, and there is not enough time for colleagues to engage in educational development.

Interviews with colleagues and the written comments on the questionnaires provide a further insight to how the barriers operate:

It is clear that the intense pressure on lecturers' time greatly inhibits their capacity to implement change. In fact, it is not simply that there is not enough time available – that colleagues feel that they are on a treadmill. There is also a lack of stability. The situation can throw up sudden demands for which there has been no previous planning. In such circumstances, there is a strong tendency to revert to 'old practices,' and to abandon attempts to implement recently acquired approaches.

Implementation of education practice is very much more than listening to an enthusiastic presentation of a development which has evolved elsewhere. It involves undertaking a critical appraisal to assure colleagues that 'it can work here', and a process of persuasion to convince them that 'it should work here'. To achieve this requires time and effort.

These messages have not been lost on the UKCME. In fact, there has been an active

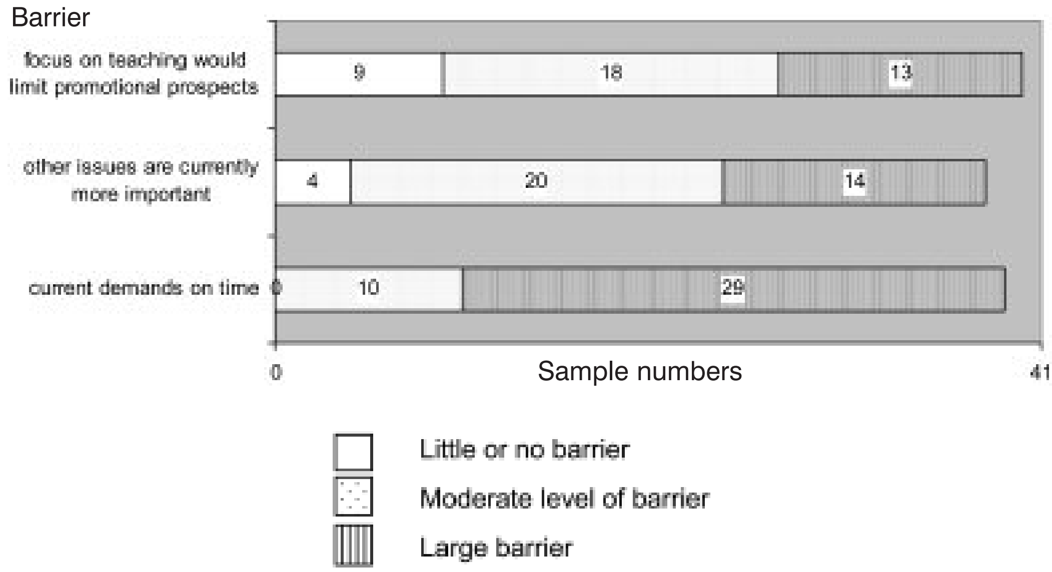

Figure 1: Barriers to Development

	Setting	Duration	Target	Centre Responsibility	Intended Outcomes
Awareness-Raising Events	Workshops/ seminars	One day	● Focus on individuals or small groups from same Department ● Participants have a variety of positions / roles in a Dept, and bring range of concerns/issues	● Sets the agenda ● Presents/ facilitates learning experiences ● Undertakes evaluation	● Promote sense of community ● Increase participant capability relating to teaching and learning practice ● Some expectation that participants learn from one another
New Lecturers' Course	Residential course	Weekend	● Focus on individuals of same discipline ● Participants have similar positions/roles in a Dept, and have similar concerns/ issues	● Sets the agenda ● Presents/facilitates learning experiences ● Incorporates the 'student voice' ● Incorporates feedback from established support 'Network' ● Undertakes evaluation	● Promote sense of community ● Increase participant capability relating to teaching and learning practice ● Strong expectation that participants learn from one another ● Build supportive 'Network'
Teaching Development Grants	Departmental context	One year	● Focus on developing individual's practice in a specific Department context (requires Head of Department approval)	● Selects particular proposals for development (noting external agendas) ● Makes available guidance/ resources ● Undertakes single (optional) visit of support to identify progress ● Organises workshops for guidance/dissemination ● Makes findings widely available via Centre ● Undertakes evaluation	● Develop good practice in relation to student learning which is relevant to the Departmental context – meeting local need ● Encourage a wider uptake of education practice across the Materials discipline ● Establish a community Network ● Assist in gaining continued funding /support for further development
Supported Change Programme	Departmental context	Two years	● Focus on the whole Department, (or a sizeable component), evolving practice (with strong commitment from senior staff)	● Selects Departments appropriate for change based on the track-record of previous Centre (and other) developments ● Provides a 'package of support' on an ongoing basis ● Undertakes planning and support meetings at the Department ● Undertakes evaluation	● Promote an enhanced student learning experience within a Department on a substantial scale ● Encourage a wider uptake of education practice across the Materials discipline ● Assist in gaining continued funding/ /support for further development ● Evolve practice in relation to dissemination

Table 1 - Enhancing learning and teaching in HE: UKCME strategies compared

FROM	TO
Awareness-raising	Supported change
One-off events in central locations	Departmental context
UKCME defines the agenda	Departmental agenda
Expertise resides at the Centre	Expertise located with practitioners
Centre as broker	Centre as facilitator
Short-term participant involvement	Ongoing staff involvement within the Department
Promotes capability of the teacher	Encourages enhancement of the learner experience

Table 2: Shifts in UKCME emphasis: moving from traditional to latest strategy

response to evolve its practice in the light of evaluation evidence.

EVOLVING PRACTICE

Although the strategies of the UKCME have evolved separately to meet the needs of specific target groups, they are increasingly regarded as stages in a coherent development programme. Four elements of this programme are compared in **table 1**.

The traditional strategy to promote educational development through awareness-raising events has now been augmented by the Centre with strategies that focus development within the Department – and most particularly through the latest strategy the 'Supported Change Programme'. There are distinct differences between these strategies as represented in **table 2**.

The UKCME is convinced that the above shifts in emphasis must take place in order to address the barriers to implementation of change. But how does this translate into practice? This is considered in the final section of this paper.

DISCUSSION

Clearly the Supported Change Programme is in its early stages of development. Practice is still evolving. The current literature on management of change provides an invaluable insight into the issues which must be addressed.

In summary, implementation of change is a very complex process with a number of factors interacting.

An initial set of factors relate to the characteristics of the development itself (Fullan,[3] and [4]). Is there an accepted need to change? What evidence is there that it would be worthwhile? What are the pitfalls? What will be the demands on resources? Is there a requirement that new teaching skills be acquired? Has it worked elsewhere? With what results? Can it work in a place like mine, with my students?

Successful implementation means providing opportunities for colleagues to address these questions if they are to develop initiatives successfully within their own contexts (Trowler and Knight,[5]). Developers from the UKCME working on the Supported Change Programme have learned that they must provide opportunities for colleagues within the Department to engage in critical appraisal, to explore questions along the lines of 'can't it work here?' and 'should it work here?'.

A second set of factors relate to the change agents; the external bodies such as the UKCME. Can such agents provide leadership and inspiration, yet be responsive to individual needs? Is an appropriate level of support, advice, and guidance made available? Is attention paid to the social aspects of promoting development, along with a promulgation of technical implications? (Nonaka and Takauchi,[6]).

To address these questions, the developer from the UKCME must be capable of adopting a variety of roles including adviser, supporter, critical friend, locator of resources, evaluator.

A final set of factors may be defined in terms of local characteristics. The importance of institutional variables in determining change is well documented (Harman and Silver,[7]), and there is now a growing appreciation that the main driver is likely to be at Departmental level. Can lecturers be developed who can share with colleagues the necessary skills, energy and enthusiasm? Can course leaders and heads of department be influenced such that they can work towards making change possible? Is the culture of the institution and the nature of the workload amenable to successful implementation?

Such factors translate into a range of issues which are to be addressed with the UKCME developer working alongside colleagues in the Department. Issues to be explored include strengths and challenges within the Department, range of perceptions held by colleagues, resource implications, etc.

It is clear, that to address the above sets of factors successfully makes a considerable demand on the time and resources of the UKCME. Certainly a larger and more diverse commitment than that associated with simply providing awareness-raising events or providing resources for dissemination.

The 'package of support' provided by the UKCME to those Departments selected for the Supported Change Programme will have a number of elements. From the experience gained to-date by the Centre, these will include:

1. Initial meetings to focus on intended change and on the capacity of the Department to deliver change.
2. Small-scale grant funding to support learning and teaching in the Department.
3. Follow-up meetings – these can have a variety of functions including:

   - Planning a way forward
   - Exploring individual (staff and student voice) perceptions in relation to change (through away-days and interviews)
   - Exploring current practice
   - Providing critical appraisal
   - Identifying/exploring resource implications
   - Identifying gaps in resources/ awareness/knowledge
   - Ascertaining/monitoring progress to-date, and identifying potential 'obstacles' or 'blockages'.

4. Staff and student workshops in relation to development.
5. Signposts to relevant practice elsewhere.
6. Resource provision from the Centre.
7. External evaluation.

As noted above, as with all other UKCME strategies, external evaluation will be undertaken of the Supported Change Programme. This will explore issues relating to impact of the programme on educational provision – and ultimately student learning within selected Departments. But will seek also to build on the above list to ascertain what constitutes good practice in relation to each of the elements, and crucially to consider whether the funding and resource commitment made by the Centre represents value for money.

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QUALITY ASSURANCE AND UK-SPEC – AVOIDING 'THEM AND US'

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INTRODUCTION

The new procedures for accreditation of engineering courses in the UK (UK-SPEC) are based on detailed requirements in the form of learning outcomes or 'output standards' and raise some interesting issues.

Some of the issues are to do with the scrutiny of courses and of the achievements of students and staff, and can be seen as part of the wider 'quality debate' in which many academics are hostile to the methods and motivation of those who seek to impose quality assurance systems. The paper explores these perspectives, and those that oppose them.

The other main issue is to do with the relationship between individual subject lecturers and the system within which they work.

The perspective that gives the most satisfying resolution to the debate about quality assurance and also gives a helpful representation of the relationship between the individual lecturer and the system that includes quality assurance and accreditation, is the use of the term 'structure' as promoted by the sociologist Anthony Giddens.

The paper explores the 'structure' within which we work and demonstrates how understanding it can avoid 'them and us' attitudes to quality assurance and accreditation within engineering courses.

PERSPECTIVES ON QUALITY

I first consider published perspectives on quality assurance in higher education (not specifically related to engineering).

Many perspectives on quality assurance incorporate the concept of *risk*. McWilliam(1) offers the framework that 'all contemporary organizations, including universities, are risk organizations. This is because all organizations must, of necessity, focus on guarding themselves against the possibility of failure . . . For a university, this means guarding against the danger of waste (of resources), of failure (of students), of declining standards (intellectual, ethical and moral).' In the specific context of accreditation of engineering degrees, we could add to this list the danger that engineering graduates will not be professionally competent.

Morley(2) states that 'one of the emerging functions of higher education has become the aversion to risk.' Her feelings about this quickly become apparent. 'Like other neoliberal discourses, for example choice and consumer empowerment, quality assurance appears to be client-focused and democratizing, whereas it has deeply conservative underpinnings.' Morley comments on 'the group of people from which the pool of peer assessors, quality assurance officers and managers is drawn. This group can be driven by paradoxical and contradictory aims. On the one hand, they subscribe to processes that are profoundly undemocratic and authoritarian. On the other hand, there is a democratizing driver. They want a better deal for students – more information, product specification and risk-reduction in a knowledge-driven economy. The values of the consumer society are now firmly embedded in educational relationships.'

Smeyers and Hogan(3) give a more optimistic presentation of the same side of the argument, essentially presenting risk in education as a good thing. 'Perhaps the risks of education that are most worth taking are those that humanely bring to light undetected but invidious preconceptions and that enable learning in any field to proceed as a distinctively human endeavour with a perceptive sense of its own possibilities and limitations.'

The alternative view, in the form of a robust defence of quality assurance systems in higher education, and regret they do not go further, is given by Randall(4). 'Both students and employers, the main users of the higher education system, need to have confidence that qualifications attest accurately to past achievements and current ability.' Randall predicts that 'the combination of circumstances that gave rise to complaints about financial products that failed to live up to expectations could easily give rise to similar complaints about investments in higher education that failed to deliver what the user expected . . . Many young parents will now be investing to meet the costs of the higher education that their children will be entering in ten or fifteen years' time. It would be ironic if their savings schemes turned out to provide more effective and transparent safeguards and better public information than the higher education those savings are intended to purchase.'

Commenting on reluctance in higher education towards further development of quality assurance systems, Randall feels that 'that reluctance is a symptom of an attitude that puts the interests of the providers above those of the users . . . For too long the providers of higher education have behaved like princes of all they survey. It is time for the consumer to be king.'

UNIVERSITIES AND EMPLOYER INTERESTS

Some commentators emphasise the value and importance of universities which are genuinely *independent* (though the examples generally come from the past). Describing the establishment of the University of Virginia, Smeyers and Hogan(3) quote from a letter by Thomas Jefferson: 'this institution will be based on the illimitable freedom of the human mind. For here we are not afraid to follow truth wherever it may lead, nor to tolerate any error so long as reason is left to combat it'. This emphasis 'clearly distinguishes the enduring interests of *education* from the interests of politics, or religion, or commerce'(3).

Referring to the ways in which universities are having to respond to employer interests, Land(5) states: 'In order to compete successfully within a globalized economy, there are pressures for the higher education (HE) curriculum to become more vocational, for HE to be more closely linked to the needs of a global economy and employability needs.' Later he describes possible problems that may arise in consequence: 'Employability remains for many academics, however, a discourse that is located outwith their discipline . . . a form of troublesome knowledge, an alien discourse . . .'

Employer interests are referred to by most writers on quality assurance, including those quoted from above. Morley(2) points out that 'while higher education is largely dependent on state funding, it is expected to meet the requirements of the private sector economy. Increasingly, higher education is being framed as a source of labour market training. There is a more explicit concern with universities producing new workers.' Later she comments on the important fact that 'professional knowledge has become unstable. The old notion of banked knowledge, whereby professionals acquire a body of knowledge in their youth and then practise throughout their careers, is changing. There is increasing emphasis on disposable, transferable and just-in-time knowledge.'

Randall, as might be expected, emphasises the responsibilities of universities to satisfy employers' needs. 'There are two categories of user whose requirements must be considered. The first comprises actual and potential students and their families; the second comprises employers, professional bodies and all of those concerned with the mix of skills required in a modern economy . . . Employer interests will be concerned with abilities of graduates to perform effectively in a variety of roles. Some will seek occupationally specific skills … Most will seek more general abilities, particularly the problem-solving skills that are transferable to many contexts … For the employer interests, it is standards of both general and specific competence that matter.' (Randall[4])

PERSPECTIVES ON ACCREDITATION

In what ways are the perspectives given above, on quality assurance and the involvement of employer interests, relevant to the new Engineering Council (UK) requirements for accreditation of engineering courses as set out in UK-SPEC (Engineering Council[6])?

UK-SPEC could certainly be seen as a way of guarding against risk. It attempts to guard the engineering profession against the risk of employing graduates who are professionally incompetent. To some extent it guards universities against the risk of giving degrees to graduates who might become a liability to their employers, and therefore guards universities against the risk of developing a bad reputation in the industry. Indeed if professional knowledge is unstable, as observed by Morley, perhaps academics should see UK-SPEC not as an imposition but as a reassuring guarantee: the industry helpfully saying to academics, ‘teach this and everyone’s happy’. In a sense, the Engineering Council is accepting responsibility for this risk and protecting universities.

On the other hand UK-SPEC clearly raises issues about the independence of universities. The acronym itself implies that it represents the industry’s specification (detailed set of requirements), for the universities’ products (graduates). It implies that graduates whose education does not comply precisely with this specification will be treated by the industry with the same dismissiveness as a component received from a supplier that is ‘out of spec’. This can be seen as challenging the ideal state of independence of a university, though perhaps that should not be taken too far. No one would imply that UK-SPEC attempts to pervert truth in some way. At its worst it might stunt educational ambition by limiting the options of academics, in terms of content and approach. And it should be pointed out that no engineering academic should find employability an ‘alien discourse’, in the way Land(5) considers some academics might.

John Randall would see UK-SPEC as very consistent with his vision. Even the format of the learning outcomes specified (general learning outcomes and specific learning outcomes in engineering) mirrors his ‘standards of both general and specific competence’.

A further important perspective is the relationship between the individual lecturer and the system that includes quality assurance and accreditation, in the context of implementing UK-SPEC. I consider this next.

IMPLEMENTING UK-SPEC

The learning outcomes in UK-SPEC must ultimately be achieved at the level of the whole course. Yet student learning is facilitated by lecturers within individual subject units – ‘modules’ as they are termed at most universities. Of course student learning may actually take place at the level of the course; for example when a student is working on a project she may find herself integrating knowledge from different modules. But the ‘delivery’ of content, and even the creation of learning experiences that encourage integration of knowledge, all reside within discrete modules.

Modules may be delivered by one or more lecturers, but ownership of module design rests with one member of staff – often termed the ‘module leader’. The module leader is a member of the group who collectively deliver the course as a whole. It is clearly desirable for module design by the module leader to be influenced by discussions at group level, and the process must be steered to some extent by the manager of the course or of the group. But the changes that must be made to a course in order to comply with UK-SPEC will ultimately be made by individual module leaders working on the content of individual modules.

Therefore the relationships between individual members of staff, the group of staff, and the system within which they work, are important and interesting. It is helpful to borrow some concepts from sociology on the relationship between individual action, or agency, and overall structure.

AGENCY AND STRUCTURE

The British sociologist Anthony Giddens ‘claims that structure and action are two sides of the same coin. Neither structure nor action can exist independently; both are intimately related. Social actions create structures, and it is through social actions that structures are produced and reproduced . . .’ (Haralambos and Holborn[7])

Element of structure	Mechanisms
Module descriptor	Module leader's ideas and reflection
Teaching and assessment norms	Interaction between lecturers: informal, formal within an institution (observation, moderation); subject centre workshops, international conferences
Internal quality assurance	As peer reviewers, panel members
Student feedback	By anticipating/responding
External examiners	By 'educating' externals; by acting as externals elsewhere
Modular system	By providing feedback on operation, and proposing changes
Programme specification	Via group discussion and changes to modules
QAA; Benchmark statement	By providing feedback on experiences, lobbying via groups of senior academics; by particular interpretation
Accreditation visits; UK-SPEC	By membership of panels or lobbying those who are members of panels; by particular interpretation

Table 1: Interaction between individual action and the structure

In this sense, the ‘structure’ is not an imposed system within a ‘them and us’ world. ‘It is agents who bring ‘structure’ into being, and it is ‘structure which produces the possibility of agency.’ ‘Structure is both enabling and constraining.’ (Cassell[8])

An important concept is the ‘duality’ of structure in the sense that ‘the structural properties of social systems are both the medium and the outcomes of the practices that constitute those systems’. (Giddens [9]) ‘The ‘duality’ of structure consists in structure’s two-sided existence – as both the medium and the unintended outcome of social practice.’ (Cassell[8])

The example that is commonly given is related to language. When we speak, we are making use of the conventions of language, yet through use of language individual speakers may cause those conventions to change over time. An example more closely related to higher education might be assessment. When we give a piece of work 60%, we are complying with a structure that guides the determination of marks, yet through our own marking practice and the debates we have with colleagues whose marks we are moderating, we may also be confirming the structure, or perhaps developing it, or even challenging it. A mark is only given to work of a particular quality because, at that time, some ‘structure’ of mutual understanding condones it.

So in higher education what is the ‘structure’ in its entirety? It is not just (for example) the modular system, or the course learning outcomes, or the requirements of accreditation. It includes many other enabling and constraining factors including all shared understanding about good practice. Good practice in engineering education must include relevance to industry, and the individual lecturers (the agents) need a system, or a component within the ‘structure’, to enable this (UK-SPEC perhaps).

We would not be making proper use of these ideas if we simply defined this structure as UK-SPEC by itself. But perhaps we would be making proper use of the concepts if we used a fuller definition: that the structure consists of the entire enabling and constraining system, including peer-moderated good practice, quality assurance procedures, UK-SPEC, student questionnaire feedback, and so on.

This is developed more fully in the next section.

An example of interaction between agents and structure in this case is the fact that academics have influenced the development of UK-SPEC, and will be heavily involved in its ‘imposition’ and ‘policing’ by their membership of visiting accreditation panels.

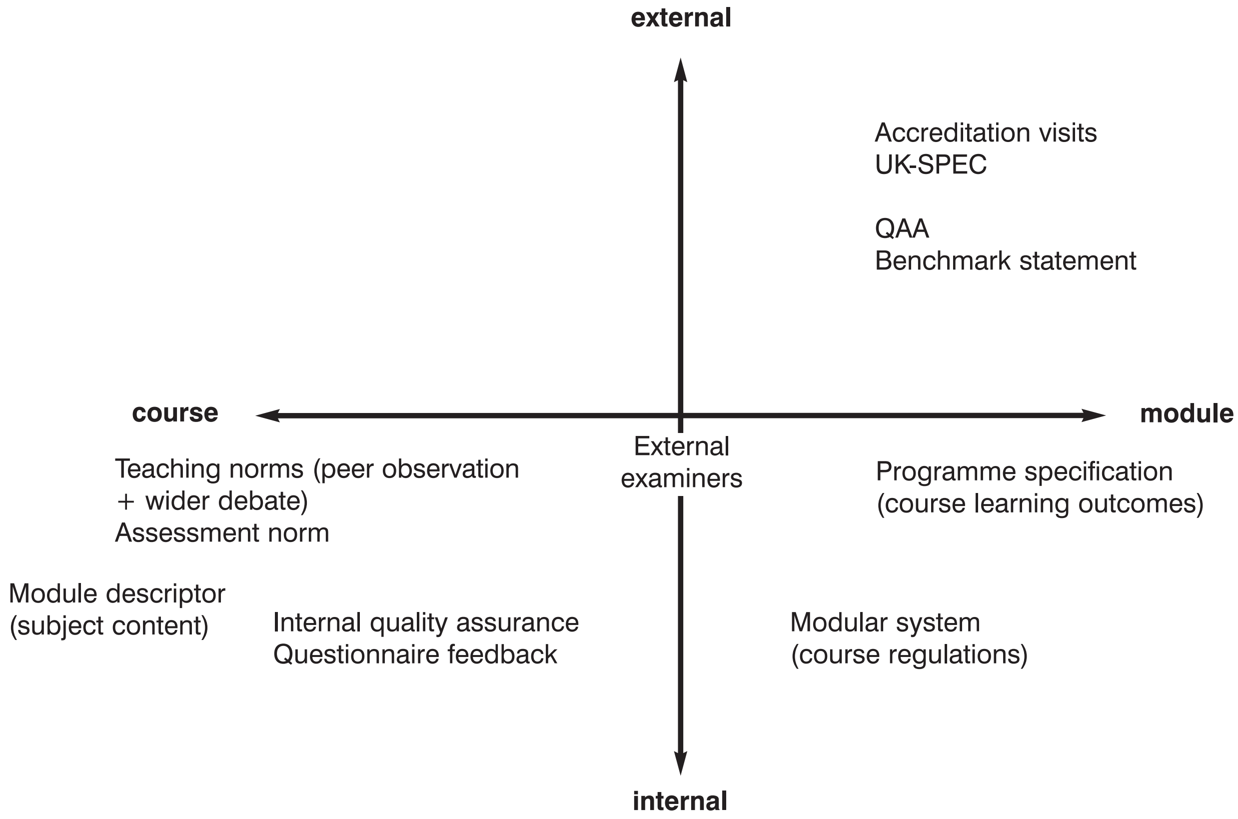

Figure 1: The 'structure'

THE 'STRUCTURE'

I attempt to represent this structure as a whole in **figure 1**.

This is an attempt to represent the system as fully as possible. It includes both academic quality assurance and professional accreditation, set out on an ***internal–external*** axis. The relationship between the individual lecturer and the group is represented by the axis that is equivalent in delivery terms: the ***module–course*** axis. Some sense of scale (as opposed to a simple binary split) is intended along both axes.

How do the elements of this structure display Giddens' 'duality', in which 'the structural properties of social systems are both the medium and the outcomes of the practices that constitute those systems'? The likely mechanisms of interaction between the individual and the structure are given in **table 1**. For some elements the interactions between individual action and the structure are more immediate than for others, and this is confirmed by the layout of **figure 1**. But we should remember the classic example of duality related to language, given in section 7: when we speak, we are making use of the conventions of language, yet through use of language individual speakers may cause those conventions to change over time. However every time we speak we do not transform the rules of language at a stroke. The effect may be very gradual, and, to fully comply with the Giddens concept, unintended.

CONCLUSIONS

In my view it is self-evident that 'them and us' simplifications cannot be the basis of a healthy attitude towards quality assurance in higher education. For example the opinions of Morley(2) given earlier seem to go beyond simple concern about the impact of quality assurance systems, to suggest an almost personal animosity towards those that volunteer to become involved in the processes as peer assessors. In the same section, the language of Randall(4), promoting tighter procedures than those that currently exist, also seems unhelpful. The last thing we need is for quality assurance in higher education to be depicted as a contest between the interests of academics and those of the 'consumers'.

I feel that the definition and exploration of 'structure' given in the paper provides a satisfying resolution to this debate.

This 'structure' also gives a helpful representation of the relationship between the individual subject lecturer and the system that includes quality assurance and accreditation. The concept that the structure is both enabling and constraining is particularly relevant. UK-SPEC is intrusive (constraining) because it is prescriptive about content (in the form of learning outcomes at least), but, as has been stated, good practice in engineering education must include relevance to industry and in this context UK-SPEC is enabling. As I have suggested, this could even be interpreted as the Engineering Council taking away from universities some responsibility for the risk that engineering graduates will not be well prepared for their careers.

Engineering departments all over the UK are adapting their courses to comply with UK-SPEC. Steered by discussion with colleagues and coordinated by those responsible for management of the course and of the group, the main changes will be made by individual lecturers working on the content of individual modules. Their work will be enabled and constrained by a system or 'structure' that includes UK-SPEC but also contains many other elements including all shared understanding about good practice. The structure exhibits a 'duality' in which the structural properties of the system are both the medium and the outcomes of the practices that constitute the system. For some elements the interaction between individual action and the structure is more immediate than for others. The representation on Figure 1 suggests that UK-SPEC lies in the part of the structure that is most remote from the influence of the individual lecturer but is nonetheless still part of an overall enabling (and constraining) structure.

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THE IMPLICATIONS OF THE CDIO INITIATIVE FOR ENGINEERING EDUCATION IN THE UK

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ABSTRACT

The collaborators in the CDIO Initiative have developed a comprehensive methodology for redesigning engineering degree programmes. The methodology is described along with the associated CDIO Principle, Syllabus and Standards. The relevance and implications of the CDIO Initiative to engineering education in the UK is then discussed, and it is argued that adoption of the CDIO approach by engineering schools in the UK is both timely and appropriate.

THE CDIO INITIATIVE

The CDIO Initiative is a major international initiative to reform engineering education. The founding members, who launched the initiative in 2000, were MIT and three leading Swedish universities. Two years ago Queen's University Belfast was invited to join, and subsequently the number of universities involved has increased to nineteen. The CDIO collaborators now include universities from the USA, Sweden, Canada, Belgium, Denmark, Germany, South Africa, Singapore, China, New Zealand and the UK. The UK universities involved, apart from Queen's University Belfast, are the Universities of Liverpool, Bristol and Lancaster.

Following a decision to form local CDIO groups in different regions of the world, Queen's University and the University of Liverpool were appointed as the joint CDIO Regional Centre for Ireland and the UK. To date, engineering schools from 13 universities have attended meetings of the UK and Ireland Regional Group, and a similar number have expressed an interest in joining the group.

Over the last five years the collaborators in the CDIO Initiative have developed a logical methodology for designing or redesigning engineering degree programmes. The methodology is derived from a guiding 'CDIO Principle' which states that engineering graduates should understand how to conceive, design, implement and operate the products and systems associated with their discipline. The conceive, design, implement, operate sequence is a shorthand description of the life-cycle of a product or system (and is also the source of the acronym that gives the CDIO Initiative its name). The CDIO methodology incorporates a detailed description of the knowledge and skills that engineering students should acquire, in the form of a 'CDIO Syllabus'. It also includes a set of 'CDIO Standards', which describe the key features that an engineering degree programme should have. The following sections describe the CDIO Principle, Syllabus and Standards in more detail.

THE CDIO PRINCIPLE

The importance of the CDIO Principle is that it focuses engineering education on the need to prepare students to become engineers. Engineering is a creative activity with an end product that is normally a physical entity. Engineers may be involved in any or all of the stages of the life-cycle of the end-product. CDIO's description of this life-cycle includes 'conceiving' and 'designing', which are self-explanatory. 'Implementing' concerns the conversion of a design into a product or system, and 'operating' covers the rest of the life-cycle until the product or system is disposed of, or recycled for further use.

Engineers need to have the competence to deal with all four CDIO stages, although the emphasis will vary depending on the specific role of the engineer. Engineers primarily involved in design, for example, will have expertise in the methods and techniques used at the 'design' stage. However the ability to 'conceive' new products and systems is equally important in competitive global markets where companies need to become more innovative in order to survive. In addition, engineering designers must have a sound knowledge of the ways that their designs may be ‘implemented’, and need to pay attention to the ‘operating’ stage, if only because of contemporary concerns about sustainability. Engineers employed in manufacturing are most obviously involved in the ‘implementing’ stage. However, their knowledge of the manufacturing requirements of products and systems must be coupled with the competence to ‘conceive’, ‘design’ and ‘implement’ appropriate manufacturing facilities, while taking ‘operating’ issues such as reliability and maintenance into account. Finally some disciplines such as industrial engineering are directly concerned with ‘operating’ systems that need to be managed and controlled. However knowledge of the operating system must be combined with the ability to ‘conceive’, ‘design’ and ‘implement’ appropriate systems for managing and controlling the operating system involved.

If it is accepted that the distinguishing feature of the work of engineers is that it concerns the conception, design, implementation and operation of products and systems, then clearly this should be the major factor in the way that engineers are educated. Specifically, all students should understand how to conceive, design, implement and operate the products and systems associated with their discipline. In addition, disciplinary knowledge, and engineering science in particular, should be taught within the ‘context’ of the CDIO description of the role of the professional engineer.

At present, engineering education does not normally address the implications of the CDIO Principle highlighted above. Instead, coverage of the CDIO stages is often limited to training in the use of design tools such as CAD, while the teaching of engineering science tends to be regarded as an end in itself. Rectifying this situation does not mean that the engineering science content of degree programmes should be dramatically reduced. However it does mean that the emphasis should be on learning to use the relevant engineering science to support decision making at appropriate points in the product or system life-cycle.

THE CDIO SYLLABUS

The CDIO Syllabus was developed to provide a comprehensive description of the knowledge and skills that engineering graduates should have. The full syllabus is contained in a document which is 11 pages long (Crawley[1]). Only the main headings are shown in **table 1**.

The first section of the syllabus is a placeholder for the technical knowledge to be included in the programme. The next two sections cover the personal, professional and interpersonal skills that students should develop during the programme. These skills need to be acquired if graduates are to be competent and responsible individuals who are able to work effectively in a modern team-based environment.

The fourth section of the syllabus relates to the requirement of the CDIO Principle that students should understand how to conceive, design, implement and operate products and systems. However engineering decisions cannot be made in isolation, as enterprise, business, external and societal factors have to be taken into account. Hence, as indicated in **table 1**, the curriculum should also deal with this wider context, if graduates are to assume roles as professional engineers.

The CDIO Syllabus is intended to be a starting point in a process that leads to required learning outcomes for an engineering programme. The process, which forms part of the CDIO Methodology, is shown in **figure 1**.

In **figure 1** the CDIO Principle is an input to the degree programme in the sense that it provides the overall context. It is also an input to the CDIO Syllabus, since it contributes directly to Section 4 (see **table 1**). The main headings of the CDIO Syllabus are generic, but it will normally be necessary to customize the content at lower levels of detail for a specific degree programme, as shown in **figure 1**. Since the CDIO Syllabus is comprehensive it will inevitably produce a long list of learning outcomes. Some indication of the relative importance of the different learning outcomes will be required, in terms of the expected levels of student proficiency. In the CDIO Methodology this is obtained by issuing questionnaires to the stakeholders in the

1. Technical Knowledge	
2. Personal and Professional Skills	
2.1	Engineering Reasoning and Problem Solving
2.2	Experimenting and Knowledge Discovery
2.3	System Thinking
2.4	Personal Skills and Attributes
3. Interpersonal Skills	
3.1	Teamwork and Leadership
3.2	Communications
4. Product and System Building Knowledge and Skills	
4.1	External and Societal Context
4.2	Enterprise and Business Context
4.3	Conceiving
4.4	Designing
4.5	Implementing
4.6	Operating

Table 1: Main headings of the CDIO syllabus

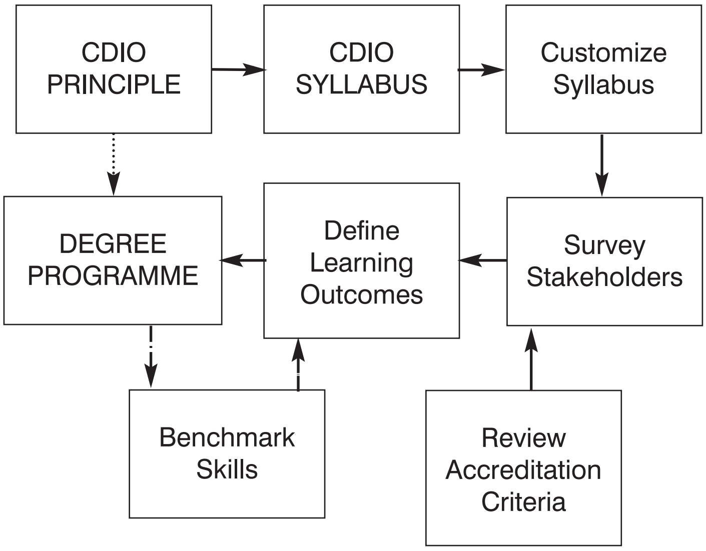

Figure 1: The CDIO methodology: defining programme learning outcomes

degree programme, which may include employers, alumni, current students and staff. In addition input should be drawn from criteria published by the programme's accrediting body. Since the accreditation criteria will normally refer to a subset of the topics in the CDIO Syllabus, this will serve primarily to highlight learning outcomes that the accrediting body regards as important.

When an agreed list of learning outcomes is produced for the programme, it will be necessary to establish which outcomes are already being met. The programme documentation will not normally provide this information for learning outcomes relating to the development of student skills. Hence it will be necessary to audit the programme in terms of skills currently developed, so that they can be benchmarked against the skills in the required learning outcomes, as indicated in **figure 1**. The programme content will then be revised in order to address both skill and knowledge based learning outcomes that are not currently met.

THE CDIO STANDARDS

The quality and relevance of a degree programme depend on other factors apart from the content of the curriculum. These include the teaching and learning methods used, the competence of the staff and the availability of suitable learning spaces. The purpose of the CDIO Standards (Armstrong[2]) is to provide benchmarks for these other factors, while at the same time reflecting current best practice in engineering education. There are twelve standards in total, but for the purposes of this paper it is appropriate to briefly describe the following four, since they relate directly to teaching and learning and curriculum design.

Standard 3 requires an integrated curriculum where disciplinary subjects are mutually supporting, and a specific plan to integrate the development of personal, professional, inter-personal and product and system building skills.

Standard 4 requires an introductory course in the first year which includes hands-on experience that starts the development of product and system building skills, demonstrates that engineering science can be applied to practical problems and provides students with essential personal and interpersonal skills.

Standard 5 requires a curriculum that features two or more design-build exercises, including an advanced project that covers all four CDIO stages along with the need to take business and societal factors into account.

Standard 8 requires an approach to teaching and learning based on active experiential

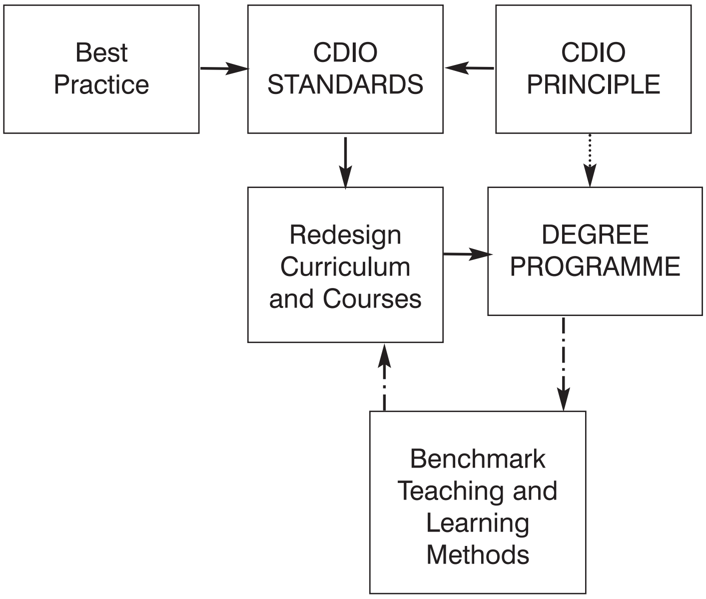

Figure 2: The CDIO methodology: curriculum and course redesign

learning principles, not only through project work, but also in lecture classes.

Figure 2 shows how the CDIO Standards that deal with teaching, learning and curriculum design fit into the overall CDIO Methodology.

As indicated in **figure 2** it will normally be necessary to identify the teaching and learning methods currently used, so that they can be benchmarked against those stipulated in the CDIO Standards.

The main advantages of the CDIO Methodology outlined in **figures 1 and 2** are that:

- It incorporates a guiding principle that defines the overall aim of engineering education, and provides a rationale for determining what and how students should be taught.
- It features a systematic process for defining learning outcomes that is informed by stakeholder input.
- It combines the guiding principle with acknowledged best practice as the basis for curriculum and course redesign.

IMPLICATIONS FOR ENGINEERING EDUCATION IN THE UK

The research role of universities in the UK has taken precedence over their teaching role in recent years. As a result, academic staff tend to be recruited on the basis of their research expertise rather than their teaching interests or experience. Since engineering science underpins most active research areas, a concern is that this is likely to reinforce the view that engineering science should be taught as an end in itself. It is therefore important that engineering schools in the UK become proactive in ensuring that their degree programmes meet the needs of the bulk of their students, who will become practicing engineers. CDIO is clearly a possible vehicle for this. Furthermore, experience suggests that the majority of staff in engineering schools, whatever their backgrounds, can be convinced of the merits of CDIO, mainly because it is based on logical arguments. Hence there is reason to believe that the growing interest in CDIO in the UK is both timely and important, since it provides a means of countering the negative impact of the current emphasis on research.

Implementing change in UK engineering schools is difficult, mainly because of the current demands on staff time (including those generated by the Research Assessment Exercise). On the face of it implementing CDIO would appear to require major alterations to engineering curricula and the way that engineering students are educated. However some elements of CDIO are already in place in UK engineering education, and in practice implementing CDIO is more a question of the further development of these elements rather than radical change. In order to justify this claim it is necessary to consider briefly how past reforms have shaped engineering education in the UK.

Historically reform in UK engineering education has been driven by national initiatives such as Dainton, Finniston and SARTOR. As a result, engineering programmes acquired additional features such as business courses, content on engineering applications and team-based projects in the final year. More recently UK-SPEC focused the attention of engineering educators on learning outcomes rather than programme content. In the following sections it will be argued that CDIO builds on or extends these and other developments that have occurred in recent years.

Thinking Beyond Design

Reports and articles published in the UK have for many years highlighted the importance of design in engineering education, and UK engineering programmes generally include specific courses in design. SARTOR 3 stated that 'an accredited engineering degree course is expected to be taught in the context of design, so that design provides an integrating theme' (The Engineering Council[3]). This statement is echoed in the CDIO Principle, except that 'design' is replaced by the life-cycle sequence 'conceive, design, implement and operate'. As a result, the importance of creativity and innovation is stressed, the fact that engineers need to be able to implement their designs is included, and the need to take the subsequent use of the products and systems into account is underlined. However CDIO can be regarded as an extension of the focus on design in the UK, in order to encompass all stages of the end product life-cycle.

An Enhanced Approach to Learning Outcomes

The publication of UK-SPEC as the successor to SARTOR heralded a change in direction to outcomes-based accreditation (The Engineering Council[4]). The document lists required learning outcomes under the headings shown in **table 2**, but makes no reference to curriculum design or the pedagogical methods to be used.

A. General Learning Outcomes
1. Knowledge and Understanding
2. Intellectual Abilities
3. Practical Skills
4. General Transferable Skills
B. Specific Learning Outcomes
1. Underpinning Science and Mathematics, and associated Engineering Disciplines.
2. Engineering Analysis
3. Design
4. Economic, Social and Environmental Context
5. Engineering Practice

Table 2: UK-SPEC learning outcomes: main headings

Most engineering educators would agree that engineering graduates should achieve the learning outcomes listed in UK-SPEC. However no rationale is presented for the choice of learning outcomes included in the list. It is therefore difficult to judge whether or not the list is complete. In contrast, the CDIO Syllabus is based on a rationale that it must satisfy the overall aim of engineering education, as defined in the CDIO Principle. This leads to a coherent and complete list of competencies that graduates should have.

When the CDIO Syllabus is compared to UK-SPEC for completeness, it is evident that, like SARTOR 3, the latter only highlights the engineer's responsibility for design, rather than all of the life-cycle stages. It is also noticeable that UK-SPEC places less emphasis on professional skills than the CDIO Syllabus, which runs counter to many employers' expectation that students will be able to assume professional roles when they graduate. UK-SPEC groups a range of personal and interpersonal skills under the title of 'general transferable skills' and for further information refers to a set of 'key skills' published elsewhere for university level students. This means that, in contrast to the CDIO Syllabus, UK-SPEC does not identify all of the personal and interpersonal skills that are of specific importance to engineering graduates. The conclusion can therefore be drawn that, on several counts, the CDIO Syllabus is more complete than UK-SPEC and as such extends the UK-SPEC requirements to include all of the competencies that an engineering graduate could reasonably be expected to have.

The CDIO Syllabus is of course a syllabus, which ultimately becomes a set of learning outcomes. The CDIO Methodology requires that the syllabus be first customized for the degree programme concerned, and then validated and refined by consulting stakeholders. The consultation process has been found to be valuable because learning outcomes can vary in importance depending on the engineering discipline involved, as well as the employment destinations of the graduates. (As an example when graduates are primarily employed in SMEs they will require different competencies compared to graduates employed in large companies.) Hence CDIO extends the process of defining learning outcomes by adding provision for local adjustment based on input from the degree programme's stakeholders.

Adopting Standards

UK-SPEC leaves engineering educators to decide how best to achieve its required learning outcomes. Engineering educators in turn are likely to be influenced by the significant support that exists in the UK for developments such as introducing active learning or placing more emphasis on the development of student skills. In fact, it would be reasonable to assume that there is a fair degree of unanimity as to how ideally engineering students should be educated. A logical development would be to draw up an agreed set of criteria that describe best practice, which engineering schools would then try to meet. In effect, this is what the CDIO Standards provide, and it is noted that the CDIO Standards have been adopted as the national standards for engineering education in Sweden (Malmqvist *et al*.[5]). In the UK, CDIO could build on current developments by providing a coherent set of requirements that reflect best practice in engineering education.

CONCLUSIONS

CDIO can help engineering schools in the UK to refocus on educating their students, in order to redress the imbalance caused by undue emphasis on research. The changes needed to implement CDIO do not require a change in direction, since they build on past and current developments. Hence the context of engineering education needs to be strengthened and broadened to include not only design, but the full sequence of life-cycle stages. Learning outcomes need to be extended, provided with a rationale and customized using stakeholder input. Current initiatives to adopt pedagogical best practice need to be expanded to ensure that engineering education is delivered to the highest standards. CDIO is the best option for achieving these objectives, because it represents the only coherent and comprehensive strategy currently available.

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