

Analysis and Development of Innovative Engineering Programmes

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Abstract: This paper presents a method of analysis and, potentially, design of innovative engineering programmes, mainly focusing on the level of interaction between engineering disciplines, meeting requirements for professional accreditation and meeting requirements for the skilled work-force in the place of implementation. The programmes are in line with the standards of the UK Engineering Council. Hence, design of curricula had to encompass a number of elements, and demonstrate that they are safeguarding the quality requirements of the professional engineering institutions. The core building construct is outlined. The proposition is developed that sharing components of engineering programmes of study across diverse disciplines is beneficial in preparing students for engineering of the future. Some metrics are proposed, based on fuzzy logic approach to establish membership functions for measuring interaction between the programmes, and the emphasis of the programmes on particular aspects of engineering learning outcomes. It is demonstrated how such metrics can be used in designing and analysis of modern engineering programmes. Furthermore, to exemplify the proposed approach, the paper outlines the methodology of establishing and analysing the link between academic contents and practical “shop-floor” skills, both of which are required from engineers in modern industry. It is felt that the approach used and the experiences gained may assist academics who are considering establishing similar or related type programmes of study and may also be of value to institutions undergoing transformation.

Keywords: Professional Engineering Competencies, System based curriculum design, Mapping of learning outcomes, Curriculum design, Workshop skills

1. Introduction

It is widely accepted that France, through the creation of technical institutes in the eighteenth century, formalised the engineering disciplines. The first institute, the Ecole Polytechnique was established in Paris in 1794 (Bugliarello, 1991). It is therefore justifiable to conclude that all engineering disciplines, in the time of little knowledge generation, have started from a single discipline namely military engineering as documented by Encyclopaedia Britannica (Encyclopaedia Britannica, 1779). Figure 1 shows a schematic approximation of the historical evolution of engineering disciplines as suggested by Tadmor (2006).

As knowledge in general, and particularly engineering knowledge, began to accumulate in the following years, decades and centuries, and in order to equip professionals with the appropriate total sum of skills and specific discipline knowledge, engineering education tended to continuously diverge. One may argue that the basic/fundamental disciplines of engineering are: Civil, Mechanical, Electrical and Chemical. However, as time progressed, many sub-disciplines emerged and eventually became disciplines in

their own right, for example Electronic Engineering, Computer Engineering and Manufacturing Engineering.

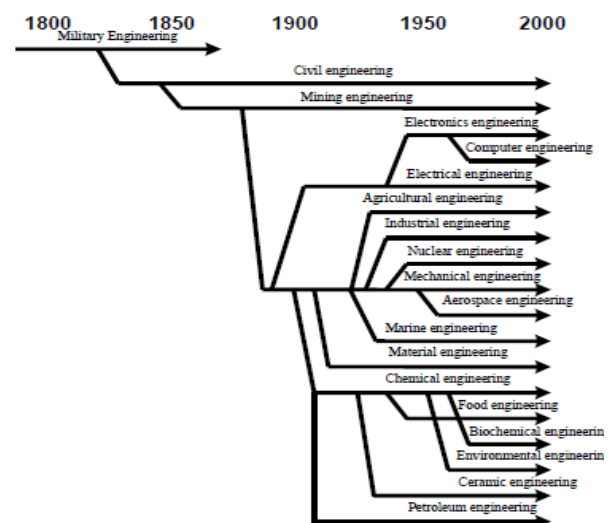


Figure 1: Branching of Engineering through time
Source: Abstracted from Tadmor (2006)

As those emerging disciplines tried to find their own identities, this was accompanied by vanishing commonalities not only between engineering and non-engineering disciplines, but also between the engineering disciplines themselves. At a point in time, these disciplines appeared to be self-contained as if not affected by the larger body of knowledge. This was noticeable until the middle of the twentieth century (Rugarcia et al, 2000).

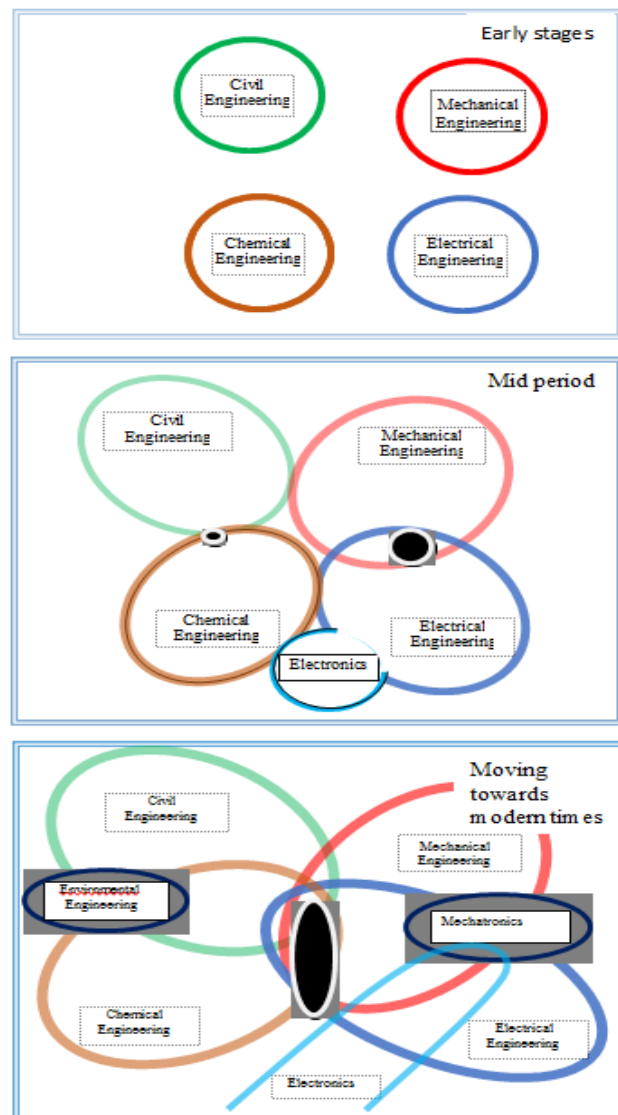
Today however, engineers do not work in isolation, but they work in the context of enterprises, cultures and communities, which represents divergent interests and perspectives. If one accepts that engineering education in the twentieth century developed based on the emerging science revolution, which led to science based curricula, then it is notable that the twenty-first century now sees the fusion of science and technology which will not only blur the difference between engineering disciplines but also between science and engineering.

In the past few decades, there has been an increasing demand for the integration of engineering education. This is accompanied by increased awareness of the vital importance of multi-disciplinary, socio-cultural and economic development, which young, successful, emerging engineers will encounter. At the same time, higher education is facing challenges, including new technologies changing the ways in which knowledge is produced, accessed, disseminated, managed, and controlled. Cultures and societies have become increasingly knowledge-based so that higher learning and research now act as essential components of cultural, socio-economic and environmentally sustainable development of individuals, communities and nations.

Consequently, the picture of contemporary engineering is a dynamic one, changing at a fast pace. To illustrate the changes, the authors propose a graphical representation as presented in Figure 2. It attempts to demonstrate the engineering disciplines with the progression of time. Discipline specialisations have matured and expanded with time and have, in part, overlapped with neighbouring disciplines (Mechanical, Electrical, Civil, Chemical Engineering), resulting in some instances, in the creation of newly formed disciplines, such as Mechatronics.

In the dynamic world of today such disciplines are not necessarily self-contained, as was the case in the past. Instead, they all draw from the increasingly common and expanding base of knowledge and tools (often software related) to solve engineering design problems. Therefore, even if new disciplines are created and named, they substantially overlap with other (old and new) disciplines.

In this article, the authors combine their amalgamated experience from working in engineering higher education institutions in different countries, to discuss aspects of analysis and design of modern engineering curricula, in particular through exploration of synergies between different engineering programmes.



Black spots indicate clusters for potential new disciplines being created.

Figure 2. Evolution and expansion of engineering disciplines over time, from earlier to later

To illustrate the concept, a proposed degree programme in Automotive Engineering is presented. The context is that of an Engineering Faculty/School comprising a number of programmes: Civil Engineering, Electronic Engineering (with focus on Avionics), Petroleum Engineering, and Automotive Engineering.

In setting out to create a new suite of engineering programmes or in revising an existing one, the attention is focused on:

- Accreditation of an engineering degree programme: successful accreditation will ensure that the programmes developed have been designed to meet the highest standards set by the engineering professions. In this paper, the authors focus on professional accreditation with the Engineering Council United Kingdom (UK), in order to afford

students in turn the opportunity to become registered incorporated (IEng), and later Chartered (CEng) engineers.

- Resource implications: In particular, the number of staff required to teach and the facilities (including laboratories and workshops) which are needed. This closely linked to the number of units of study (modules) to be attributed to a given programme.
- Needs of industry in the region of implementation of the programme: Which engineering disciplines are considered; also, which specific sub-disciplines and specific practical skills (e.g. in relation to particular technical equipment) are required.

Towards achieving the goal of satisfying the standards of professional accreditation, the requirements are set out in the document the UK-SPEC Standard for Professional Engineering Competence (UK-SPEC, 2014). The UK-SPEC requires achievement of five *Specific learning outcomes* and four *General learning outcomes*. The specific learning outcomes, as required by Engineering Council UK (ECUK, 2014) are briefly summarised below:

- Science and Mathematics (SM): Graduates are required to possess knowledge and understanding of underpinning scientific principles and methodology, thus attaining the mathematical and statistical methods necessary for their education in their engineering discipline (and beyond).
- Engineering Analysis (E): The requirement is that graduates be able to apply engineering principles, quantitative and computational methods to solve engineering problems. *Ability to use a system approach is noted herein.*
- Design (D): Focus is on the ability of developing a viable product or system to satisfy product specification. The graduates should be able to consider business needs, customer needs, product aesthetics and environmental impact. Further, they should be able to effectively explain their work to non-experts.
- Economic, legal, social, ethical and environmental context (S): It is necessary that engineering graduates be aware of environmental and societal impacts that engineering activities may impose, and are able to manage those impacts accordingly.
- Engineering practice (P): Students should encounter elements of practical engineering work while studying, prior to entering the engineering workforce as graduate professionals.

The detailed list of Learning Outcomes related to each of the above areas (from ECUK, 2014) is provided in the Appendix-1.

Reflecting on the aforementioned “specific” learning outcomes it is difficult to escape a conclusion that, although there will be components (competencies) which are specific to an engineering discipline nevertheless many components will be common across most (if not

all) disciplines. It has been recognised that commonality in “Design” can be particularly beneficial. Through focused education in design, clear emphasis is placed on integration of combined engineering and non-engineering considerations through implementation of a system’s based approach. The area wherein is potential for least overlap is perhaps “Engineering Practice”. This may only be achieved through practice in the selected discipline, often associated with specialist laboratory and/or workshop experience.

The UK-SPEC General Learning Outcomes (GT) cover, in summary, specific areas of personal development such as (i) Problem solving, communication skills, use of IT facilities, (ii) Planned self-learning (Continuous Professional Development (CPD)), (iii) Being able to plan and carry out a personal programme of work, (iv) Exercising personal responsibility.

Many of the learning outcomes (including design, economic, legal, social, environmental and ethical considerations) augment the requirements expected of today’s engineering graduates. These requirements are sometimes grouped holistically under the umbrella of “General or Transferrable Skills”.

The authors passionately believe that, of these general skills, the ability to embed the concept of student (and graduate) self-learning, is a critically important aspect in engineering (and other) programme designs. In doing so, it is vitally important that programmes be designed for accreditation at Honours level, thus including a substantial project work. An important point to bear in mind is that the “weighting given to different areas of the above will vary according to the nature and aims of the programme”, i.e. not every outcome will be covered by the same number of modules.

Both the Professional Engineering Institutions and Engineering Council UK encourage the accreditation of innovative engineering programmes to reflect the new delivery and content. It is postulated that an emphasis should be placed on a system approach and on inter-disciplinarity. Furthermore, it is proposed that this could be effectively achieved only via a holistic system based design of curriculum with substantial overlaps between the engineering degree disciplines.

The authors accept that a counter argument may be made that the ECUK learning outcomes could be delivered by developing and operating engineering programmes separately for each discipline, without inclusion of overlap. However, it is our belief that such an approach would be not effective in terms of utilisation of resources. Moreover, and more importantly, it will not be effective in terms of preparing the students for the engineering world of the future, wherein interdisciplinarity and a systems based approach to engineering education is expected to predominate.

Towards meeting the local industrial requirements, a fundamental tenet of programme design is that of Engineering Practice. Often engineering practice is

linked solely to laboratory and/or workshop experience of the related discipline of study. Hence, it is expected to differ from discipline to discipline and, even within one engineering discipline it will depend strongly on the localisation where the programme is implemented.

2. General Set-up of the Curriculum

The curriculum presented here refers to an exemplar programme, which has been created based on the authors' amalgamated knowledge and experience of different engineering colleges and universities. Its development is based on the *systems approach*. The core building-blocks of the degree programmes are as follows:

- *Problem-centric learning*: This is an approach in which students tackle a carefully constructed set of 'problems', generally engineering projects of growing scale and complexity.
- *The 'upside-down' curriculum*: This approach moves material on engineering applications to the earlier stages of education in order to motivate, more strongly, the students' interest in fundamental mathematics and science that can otherwise seem dry and indigestible.
- *Mathematics in context*: The teaching of engineering mathematics by engineers and presented in an 'applied' setting, rather than by mathematicians in a more rigorous 'proof-oriented' style that is ultimately less accessible.
- *Design orientation*: Many engineering programmes place a substantial emphasis on analysis, but creative synthesis, that is design, is a central, perhaps defining activity in engineering and must be central to a curriculum. Engineering students need design experience and in particular should, from an early stage, be working on 'real problems' with 'real customers' and in interdisciplinary teams, such as they would experience in the workplace.
- *Combining simulation, and laboratory*: The use of sophisticated simulation has transformed engineering education; however, there is no substitute for laboratory and practical training facilities. Many training organisations and their industrial partners find there is a need to develop and combine the theoretical learning with practical application. The addition of country-specific competences and the need for multi-skilling requires the introduction of innovative approaches that blend with theoretical delivery and utilising virtual learning or simulation platforms that safely and logically lead the student to real time applications in laboratories and workplaces.

The above are all connected through the central themes of *safety and sustainability*, *transferable skills development* and *management and entrepreneurship*. The approach to teaching and learning in all engineering programmes is one based on engineering systems

combined with engineering practice. Such an approach will inculcate in the students an understanding of the impacts and consequences of engineering decisions on issues of safety management, economics and environmental pollution.

3. Analysis of the Resulting Curriculum Set-up

3.1 Meeting the Requirements for Professional Accreditation: ECUK Learning Outcomes

Documentation to demonstrate that the designed programmes meet the outcomes as set out in Section 2 above, requires completion of a learning outcomes matrix. This document is crucial to demonstrating that the programme meets all the required learning outcomes. The matrix lists all the modules (units of teaching) covered by a programme of study and all ECUK learning outcomes (generic and specific). For each module, the matrix specifies wherein it contributes towards a specific learning outcome, by means of a "tick" at the appropriate cross-section of module and learning outcome in the matrix. The "tick" is therefore interpreted as a statement: "a given module belongs to the set of modules supporting a given Learning Outcome". Working with variety of academics in different countries the authors encountered different approaches to filling-in the output standard matrix. Some people tend to be quite conservative in their judgement and only tick a given learning outcome for their module if it is fully covered.

A problem with this approach is that a substantial amount of information about modules contributing to a specific learning outcome would be lost. For illustration, say a Learning Outcome: *E2. Ability to identify, classify and describe the performance of systems and components through the use of analytical methods and modelling techniques* (see Appendix 1) is covered in two modules: one focusing on analytical methods and another focusing on modelling techniques. A "conservative" academic would not tick any of those modules against the Learning Outcome E2, because none of them is realising it fully. However, those two together would fully address the requirements of this particular learning outcome.

On the other hand, some academics tend to be liberal / generous with their assessment. Taking for illustration the same Learning Outcome E2, a module can only address "ability to identify the performance of components" and still receive a "tick". Theoretically, there is nothing wrong with such approach, as long as the rest of the Learning Outcome E2 is covered somewhere else in the programme of study. (The task of the accrediting body would therefore be to verify such full coverage, based on the detailed contents of module's delivery and assessment). However, a vital information about the function and position of a given module in the bigger picture of the programme of study would be lost of at least diluted.

Therefore, it has to be appreciated that the numerical

analysis of how the ECUK learning outcomes are met, is, by its nature not an absolute or precise science and carries a degree of subjectivity. The reason for this is that a given learning outcome is generally only partially fulfilled in any given module. Taking another example: in addition to dedicated modules in higher mathematics, underpinning of mathematical concepts is normally also addressed via more generic engineering modules, including Control Systems, Signal Processing, and Thermodynamics. A question may be posed: to what extent a given module meets the requirements of a specific learning outcome? Such a question, and analysis based on answer to it, could be useful in programme design or re-design, by allocating weight of different modules to different learning outcomes. Possible answers may be: *not at all, to a small extent, partially, almost completely, or fully*. In assigning numerical values to this questionnaire a fuzzy logic tool may be applied.

Zimmermann (2000) and Meier et al. (2008) apply a fuzzy classification which the authors have adapted here to analyse the above proposition. In this approach, ϵ an element x is classified as belonging to a set Λ with a degree of membership, called membership function μ .

$$\mu_{\Lambda}(x) := c \text{ where } c \in (0,1) \quad (1)$$

This is in contrast to “crisp” classification where:

$$1_{\Lambda}(x) := \begin{cases} 1 & \text{if } x \in \Lambda \\ 0 & \text{if } x \notin \Lambda \end{cases} \quad (2)$$

In fuzzy classification, for individual members, the value of the membership function may vary between 0 and 1. Considering as elements the *modules* on the programme of study, the membership functions are subjectively assigned to each module, in terms of “belonging” to a given Learning Outcome (set Λ_i).

Table 1 provides an example of fuzzy classification performed for one programme of study: Automotive Engineering. The programme has 23 modules (elements). All modules, except for the final project, have the credit value of 20 credits each whereas the final project module has a credit value of 40 credits. Hence, the total number of credits for Diploma in Higher Education is 360 and for Bachelor (honours) in Engineering (BEng) is 480 credits. The modules are as follows:

Level 3 (Engineering Foundation):

- Algebra and Geometry
- Engineering Physics
- Electrical Engineering
- Engineering Materials
- Engineering Systems Design 1
- Introduction to Electrical Machines

Level 4:

- Engineering Mathematics
- Engineering Systems Design 2
- Environmental Engineering
- Thermodynamic Systems
- Thermal Systems Engineering 1
- Mechanical Systems

Level 5 (Diploma in Higher Education):

- Safety Engineering
- Group Design Project
- Engine and Transmission
- Thermal Systems Engineering 2
- Vehicle Chassis and Aerodynamics
- Engine Management Systems

Level 6 (Bachelor of Engineering - Honours):

- Engineering Management
- Individual Project (double module)
- Engineering Maintenance
- Advanced Vehicle Design
- Alternative Energy Systems

The fuzzy membership functions of those modules are assigned for 32 learning outcomes (32 sets Λ_i $i = 1, \dots, 32$). The assignment has been performed by analysing the module descriptor for each module and by inspecting the format of its delivery. The detailed description of those learning outcomes, which comes from the specification of the UK Engineering Council (UK-SPEC, 2014; ECUK, 2014), is provided in Appendix 1.

As an example, to illustrate this approach, take Learning Outcome: *SM2. Knowledge and understanding of mathematical and statistical methods necessary to underpin their education in their engineering discipline and to enable them to apply mathematical and statistical methods, tools and notations proficiently in the analysis and solution of engineering problems*, in the module: *Thermodynamic Systems*. Analysis of the delivery plan of this module shows that 10% of time is devoted to enhancing students’ knowledge and understanding of mathematical methods (partial differential equations) and further 20% to application of those methods to solutions of engineering problems. Statistical methods are only mentioned (5%). More importantly, and consistent with the analysis above, inspecting the assessment of the module reveals that approximately 20% of the marks which can be obtained are related to mathematical skills whereas the remaining 80% can be linked to other aspects/knowledge covered in the module. Hence, the value of membership function has been assigned as 0.2. It has to be stressed again that such assignment carries a substantial degree of subjectivity – hence fuzzy-set approach.

Nevertheless, is more accurate than “zero” or “one”. The next step is to combine the learning outcomes into groups, as specified by ECUK. This can mean for example that the sets: SM1, SM2, SM3 are added together to form a single set: Science and Mathematics. The membership of each element in this new set (sum of three) is defined, according to Fuzzy logic rules, using the Max function (x OR $y = \text{maximum}(\text{truth}(x), \text{truth}(y))$). Hence:

$$(x \in \Lambda_1) \text{ OR } (x \in \Lambda_2) \text{ OR } (x \in \Lambda_3) = \text{Max} \{ (\mu_{\Lambda_1}(x)), (\mu_{\Lambda_2}(x)), (\mu_{\Lambda_3}(x)) \} \quad (3)$$

Table 1. Fuzzy Classification of the Learning Outcomes

Bachelor in Mechanical Engineering (BEng) Honors (specialisation: Automotive Engineering)	Algebra and Geometry	Engineering Physics	Electrical Engineering	Engineering Materials	Engineering Systems Design 1	Introduction to Electrical Machines	Engineering Mathematics	Engineering Systems Design 2	Environmental Engineering	Thermodynamic Systems	Thermal Systems Engineering 1	Mechanical Systems	Safety Engineering	Group Design Project	Engine and Transmission	Thermal Systems Engineering 2	Vehicle Chassis and Aerodynamics	Engine Management Systems	Engineering Management	Individual Project	Engineering Maintenance	Advanced Vehicle Design	Alternative Energy Systems
	Science and Mathematics																						
SM1	1.0	0.7	0.6	0.4	0.6	0.3	0.2	0.5	0.3	0.6	0.3	0.4	0.3	0.3	0.5	0.2	0.4	0.7	0.5	0.4			
SM2		0.3	0.3	0.4		1.0	0.2	0.1	0.2	0.3	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.3	0.2	0.1	0.2	0.1	
SM3																				1.0	0.8	0.8	
Engineering Analysis																							
E1		0.8	0.6	0.5	0.4	0.6			0.8			0.5		0.8	0.6	0.5	0.5			0.3	0.8	0.6	
E2					0.4		0.2						0.7					0.6	0.7	0.6	0.6		
E3	0.2	0.5	0.8	0.3	0.5	0.7	0.2		0.4	0.6	0.5		0.6	0.6	0.7			0.7	0.9	0.3			
E4								0.9		0.3			0.5		0.5	0.5	0.7	0.3		0.2	0.7		
Design																							
D1					0.4		0.6						0.6		0.2			0.7	0.8	0.5	0.3	0.6	
D2	0.1				0.6		0.1	0.7	0.5	0.4		0.2	0.9	0.5	0.4		0.6	0.7	0.8	1.0		0.4	0.7
D3					0.4			0.5			0.3			0.5		0.3		0.8	0.8	0.9			
D4					0.3		0.6				0.2		0.6		0.5	0.2	0.7	0.8		0.6	0.5		
D5					0.7		0.9											0.4					0.2
D6					0.4		0.7						0.9					0.6	0.9				
Economic, legal, social, ethical and environmental context																							
S1				0.2	0.6			0.8	0.5				0.9			0.1	0.3	0.8	0.8	0.8			
S2				0.5	0.6			0.7					0.8					1.0		0.8			
S3					0.2			0.4										1.0		1.0			
S4				0.3	0.5			0.4	1.0				0.8					0.7			0.3		
S5				0.2				0.4	0.4				1.0	0.4			0.4	0.6	1.0	0.4	1.0	0.4	
S6		0.2			0.2	0.4		0.5	0.2	0.1	0.2	0.2	1.0	0.9		0.7		1.0	0.6	1.0			
Engineering Practice																							
P1					0.4				0.4		0.4			0.3	0.5			0.8		1.0			
P2		0.4	0.6	0.8	0.2	0.8		0.6	0.6			0.2			0.8	0.8	0.8	0.2		0.7	0.8	0.2	
P3		0.5	0.6	0.4		0.6				0.4	0.6	0.5	0.4		0.8	6.0	0.5	1.0			0.5	0.6	0.2
P4				0.4				0.3		0.3		0.3		0.7	0.4			0.3	1.0		0.3		
P5				0.5					0.4				0.8					0.9					
P6													0.8			0.8	0.6	1.0		1.0	0.6	0.4	
P7																		1.0		0.8			
P8																		0.6	1.0	1.0	0.2		
P11					0.8	0.2		1.0					0.4	1.0				0.6		0.6	0.2		
General Learning Outcomes																							
GT 1					0.5		0.2	0.6	0.4				0.4	0.8		0.1		0.4	1.0	0.3			0.2
GT 2					0.3			0.5						0.8				0.4	1.0				
GT 3					0.6			0.6					0.2	0.8			0.4		1.0	0.2	0.1		
GT 4					0.2			0.4					0.8					0.5	0.8				

In the final stage, the modules are grouped into three sub-sets with respect to their sharing status. “Sharing” identifies the modules as: shared with all other departments (A), shared with some other departments (S), and not shared (N). For each sub-set of modules, the membership function in a given Learning Outcome is calculated as an average (rather than a maximum) of the individual members functions. The result is then defuzzified by scaling the membership functions to the range 0:100%.

Figure 3 shows the percentage contribution to Learning Outcomes by modules which are: Department specific, shared with other Departments, not shared. It should be emphasised that this is an illustration and it is for the Automotive Engineering specialisation only. However, from the authors’ experience, and from other departments’ specialisations at different institutions, similar shared trends emerge.

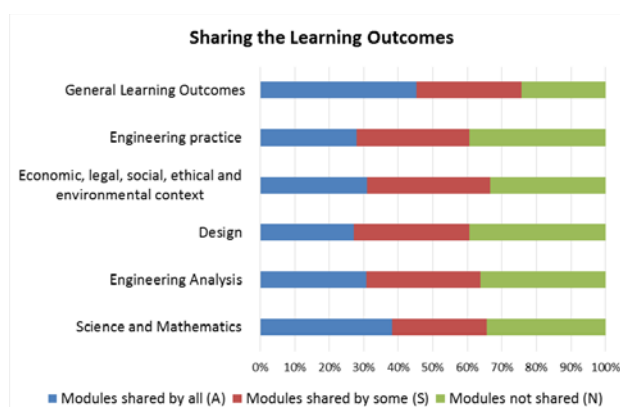


Figure 3. Assessment of contribution to learning outcomes by the modules: shared by all (common) shared by some, and not shared

Another representation of the same data is shown in Figure. 4. In this instance no scaling has been applied, hence the bar-chart places emphasis of the programme towards particular aspects of ECUK Learning Outcome objectives. As can be seen, this example is of a programme with a substantial component of Engineering Practice.

- **Science and Mathematics:** The underpinning knowledge is mainly achieved in common modules such as Algebra and Geometry, Engineering Mathematics, and Engineering Physics. Hence, a high percentage of modules are shared by all.
- **Engineering Analysis:** The required competencies are developed evenly throughout all years of study, with comparable contribution from common modules, and shared modules.
- **Design:** A high percentage of Engineering design outcomes is achieved via the specific design oriented modules at all levels of study. The design stream of the programme is based on the Melbourne model (Smith and Hadgraft, 2007), which adopts a

systems based approach. These modules are shared by some Departments, while differences are accommodated in department specific modules.

- **Economic, legal, social, ethical and environmental context:** This aspect of education is equally covered by modules common to two or more, and also to all departments. A large level of commonality is present but there are also some discipline specific aspects which must be taken into account, e.g. Electronic Engineering may share with Civil Engineering some aspects related to energy conservation (smart homes); and may share with Automotive and Petroleum Engineering, other aspects – relating for example to air pollution from combustion engines. These topics will be covered in modules shared by some, but not by all departments.
- **Engineering practice:** Herein the discipline specific modules, with associated workshop practices have a dominant effect. However, students also acquire a substantial amount of engineering practice through the laboratory and workshop sessions, which are shared among two or more departments.
- **General Learning Outcomes:** From the performed analysis it can be concluded that a majority of contribution to general learning outcomes comes from the Design oriented modules, which are common to all departments. The contribution of non-shared modules is the lowest.

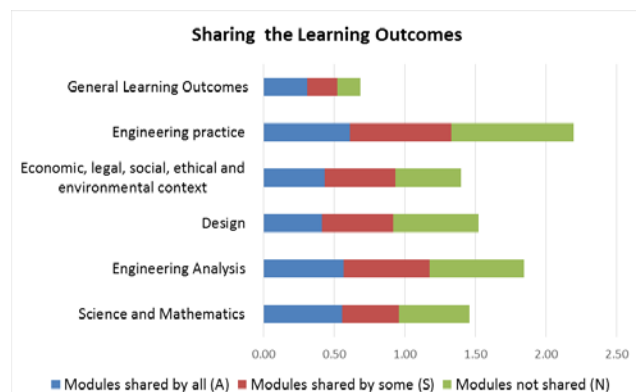


Figure 4. Assessment of the level of contribution to learning outcomes by the modules: shared by all (common) shared by some, and not shared – not scaled to (0:100%)

4. Design and Re-design Engineering Programmes

Students entering the higher education, in most cases, are doing so expecting benefits for themselves and for the society, meaning that their degrees will be recognised and valued on the job market. It is a duty of the education providers to ensure that the students’ expectations, with this respect, are met. It is therefore paramount that the engineering degree programmes are accredited, i.e. they meet all the learning outcomes, as specified, for instance, by ECUK. After fulfilling this

requirement, there is still a degree of flexibility in designing the programmes, to address the needs of local job markets and/or the emerging trends in engineering and technology. Using the fuzzy set approach, described above, can be a useful tool in addressing this goal. Assigning fuzzy membership values to different modules with respect to different learning outcomes would signify the “weight” or importance that is given to any of the learning outcomes. Hence, it will show the bias of the degree (programme of study) towards a particular profile of the graduate.

The analysis presented above would enable the educators to take a holistic view of the programmes of study, to examine how the development of different types of abilities in students progresses in time – by year of study, and in space – by module/unit of study. Furthermore, it could be assessed whether some of the learning outcomes require further expansion in the programmes, or, perhaps contraction. From the performed analysis, the attention can be then directed to specific modules.

If a new or modified degree programme is considered for introduction, to an institution already running accredited programmes, the analysis presented above will be helpful in assessing how such a programme could share modules with other existing programmes. Starting with the desired profile of the graduate, firstly, the technical contents of a programme would be established. This may result in a provisional list of new modules that need to be developed. Next stage would be to map the profile into “weights of contribution” of specific learning outcomes. Further, a function showing contribution to learning outcomes in existing programmes (similar to Figure 4) would be compared with the desired profile of the graduate, hence showing gaps and identifying those learning outcomes which need to be addressed in the newly introduced modules (with their desired fuzzy membership functions). This would also indicate the resource implications. Only after this analysis, one can proceed to designing the actual contents of the modules/units of study.

As an example of this approach, consider a design of a programme of study, which is to be leaned towards practical, workshop, shop floor skills, i.e. discipline specific engineering practice.

4.1 Discipline Specific Engineering Practice

It is the authors’ experience, from their personal career backgrounds, that the usefulness and therefore the attractiveness of engineering degree programmes is proportional to the amount of practical skills, readily deployable in a work-place, which the students acquire in their term of study. For instance, most of UK universities offer so called “sandwich courses”. In those courses, students spend one year working in industry, normally between year 2 and 3 of their degree. Then, they return to University to complete the final year of

bachelor degree. Note that the “sandwich year” is in addition to the academic credits acquired during their course. Hence, all the required learning outcomes, for instance related to analytical or design skills are fully covered in the academic programme of study. The “sandwich year” equips students with additional skills, which make them more ready for the work place.

It is well documented (Brooks, 2012; Wickware 2016) that the employability indices for those students who take “sandwich courses” are much higher than for other students. Quite often, the graduates end-up working in the company where they spent their “sandwich year”. During the “sandwich year” the students work in an industrial company in different engineering positions, acquiring practical skills and experience. Those may be called “workshop” or “shop-floor” skills.

At a first glance, it may be seen to contradict earlier argument that the courses should be focused towards transferrable skills. In answer, it should be pointed out that the workshop skills can also be taught as transferrable skills, taking into account the fast changing environment of relating engineering activities. In fact, it has been observed that when the students are confronted with the reality of engineering manufacturing or maintenance, which sometimes lags behind the theoretical state-of-the-art developments, this prompts their better understanding of necessity to be prepared for change management and for continuous professional development.

Hence, the students can also enhance their design skills, by being exposed to industrial constraints and limitations of the production/manufacturing process. This is a well-known issue, and those institutions which take engineering education seriously manage it effectively, either via a module of “industrial placement”, taken for example by students during the summer break; or more extensively, as a “sandwich course” comprising one year of students’ time, fully seconded to an industrial partner. An alternative solution, presented here, is that the industrial practice is incorporated evenly during the academic year, thus being delivered in parallel with academic modules. This may pose a logistical challenge but the advantage is that the development of engineering practical skills can be synchronised with students’ progress in theoretical aspects, delivered in other modules.

Additional motivation in development of this particular approach is in compliance with ECUK requirements for “engineering practice”, as explained earlier. A further factor, in this particular course design example, is to comply with country-specific skill needs; in the knowledge that some students will choose to graduate at Level 5 Diploma in Higher Education and will be seeking employment in a more ‘technician’ oriented role. Hence, the requirements specific to the country of operation must be taken into account.

To illustrate how these requirements are placed within the students' programme of study, one example, of one particular industry specific qualification, which is also called "commercial trade", is presented. The term "trade" is commonly used, e.g. in UK vocational education systems. Here it signifies bridging the gap between academic and vocational qualifications and will be used in the following sections. The trade is Vehicle Mechanics. In its simplified form, the requirements state 14 competencies, which the student must acquire, as follows:

- AS1 To be able to read and draft engineering drawings
- AS2 Have familiarity with basic automotive troubleshooting
- Be able to:
- AS3 Service hydraulic automotive systems
- AS4 Use automotive diagnostic equipment
- AS5 Inspect and service braking systems
- AS6 Remove and install engine components
- AS7 Inspect and repair clutch components
- AS8 Service and repair transmission systems
- AS9 Inspect and service steering systems
- AS10 Inspect and service suspension systems
- AS11 Inspect and service wheels and tyres
- GS1 Understand operational Health and Safety practice
- GS2 Perform planning of workshop activities
- GS3 Understand and implement quality standards in maintenance processes

These trade-related skills have been divided into two groups: general (GS), which are applicable to all trades, and trade specific (AS).

Acquiring of these competencies during the course of study would greatly benefit the students. Those who may complete their education at level of Diploma in Higher Education (DipHE) will be well prepared to demonstrate to future employers their skills in engineering shop-floor practices. Hence, some of the competencies can be assessed by specific, trade approved examinations – demonstrating practical skills, sometimes related to a particular manufacturer, as demanded by the country of operation.

In this example, the objective is to integrate the academic output with a set of practical skills in maintenance, troubleshooting and operation of automotive engineering equipment. From the perspective of ECUK classification, this must be supported by *Underpinning Science and Mathematics, Engineering Analysis and Engineering Design* up to the level of competency commensurate with the DipHE. Also, *General transferrable skills* are required up to the same level, whereas in *Economic, legal, social, ethical and environmental* education some aspects have to be expanded and adopted to the specific requirements. *Considering Engineering Practice*, the workshop skills requirements proposed here substantially exceed the minimum expected from accredited engineering degrees.

When designing the programmes of study, a system based approach was applied in which both the academic requirements and workshop practice requirements were

considered jointly. Hence, the analyses of ECUK Learning Outcomes and of trade needs were combined together when identifying the content and the learning outcomes of appropriate modules (units) of study. Practical skills requirements are fully completed by the end of Level 5 (Engineering Year 3), hence the students graduating with the DipHE will be fully prepared for taking up of their roles with their respective employers.

4.2 Analysis of Trade-related Requirements with Respect to the Academic Programmes of Study

From the perspective of the students, their education and their future career prospects, it is paramount that the degrees offered meet stringent international standards – in this case ECUK accreditation. At the same time, students must be prepared for their immediate future careers in industry. Hence, the students are faced with a challenging task: to combine together two highly demanding requirements; achieving their academic standards and attaining trade-related competency targets. It is our belief that through using the system based approach, by development of interdisciplinary modules, and by exploring a range of common factors in education and training, this had been made possible.

In a vocational education, each trade-related competency would, traditionally, be taught by a combination of theory and practice over a period of several weeks, potentially culminating in a trade-related examination. By applying the system based approach, a large part of the skills required is built into the academic programmes. For this particular trade (Vehicle Mechanic), 12 out of 14 competencies feature in the academic modules. They are not addressed fully in those modules, but the amount of required additional activities is reduced. The academic programme of study up to Level 5 consists of 18 modules. From this number, 15 modules contribute directly to the trade-related competency requirements.

Applying fuzzy classification, a table is generated (see Table 2), showing membership functions in each particular trade related skill for each of the academic modules and for each of the additional (trade related) modules. Allocation of the value of the membership function to each module and each trade is performed by analysing the delivery plan and assessment strategy, in the same way as was illustrated in section 3.1. Here, the programme of study is considered up to Level 5. At level 5 the trade-related programme should be completed.

The analysis is performed using the same fuzzy classification rules, as applied before. For each module, the membership into the trade specific competencies group, general competencies group, and all competencies group is calculated as a maximum (equation (3)). Next, the average is used to calculate the contribution of the academic modules grouped together and non-academic modules grouped together. The results are presented in Figure 5.

5. Conclusions and Future Work

From commencement of the 20th Century engineering practitioners and academics have debated and considered perceived needs for holistic changes in delivery of engineering higher education programmes. This paper presents an implementation of system based curriculum design in a challenging environment. The design is based on meeting the accreditation requirements of the UK Engineering Council, while at the same time emphasising and taking benefit from the multi and interdisciplinary nature of the programmes considered. An additional challenge is posed by the necessity of incorporating particular requirements for practical hand skills, which would enable students to function and to perform well in their future workplace environments.

The paper outlines the specification requirements, presents the design philosophy and discusses the methods adopted to measure the outcome. A fuzzy classification is applied, first - to assess the level of inter-disciplinarity, and, second - to assess the contribution of the academic programmes to the workshop/trade training needs. It is felt that the presented fuzzy classification approach will prove a useful tool, not only for analysis of outcomes and results but also as an ongoing assist to curriculum development and design.

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Appendix-1:

Description of Specific Learning outcomes for Engineering degrees to partially meet the educational requirements for Chartered Engineer status, cited from EC UK (2014)

Science and Mathematics (SM)

Engineering is underpinned by science and mathematics, and other associated disciplines, as defined by the relevant professional engineering institution(s). Graduates will need the following knowledge, understanding and abilities:

- SM1.** Knowledge and understanding of scientific principles and methodology necessary to underpin their education in their engineering discipline, to enable appreciation of its scientific and engineering context, and to support their understanding of relevant historical, current and future developments and technologies
- SM2.** Knowledge and understanding of mathematical and statistical methods necessary to underpin their education in their engineering discipline and to enable them to apply mathematical and statistical methods, tools and notations proficiently in the analysis and solution of engineering problems
- SM3.** Ability to apply and integrate knowledge and understanding of other engineering disciplines to support study of their own engineering discipline.

Engineering Analysis

Engineering analysis involves the application of engineering concepts and tools to the solution of engineering problems. Graduates will need:

- E1.** Understanding of engineering principles and the ability to apply them to analyse key engineering processes
- E2.** Ability to identify, classify and describe the performance of systems and components through the use of analytical methods and modelling techniques
- E3.** Ability to apply quantitative and computational methods in order to solve engineering problems and to implement appropriate action
- E4.** Understanding of, and the ability to apply, an integrated or systems approach to solving engineering problems.

Design

Design at this level is the creation and development of an economically viable product, process or system to meet a defined need. It involves significant technical and intellectual challenges and can be used to integrate all engineering understanding, knowledge and skills to the solution of real and

complex problems. Graduates will therefore need the knowledge, understanding and skills to:

- D1.** Understand and evaluate business, customer and user needs, including considerations such as the wider engineering context, public perception and aesthetics
- D2.** Investigate and define the problem, identifying any constraints including environmental and sustainability limitations; ethical, health, safety, security and risk issues; intellectual property; codes of practice and standards
- D3.** Work with information that may be incomplete or uncertain and quantify the effect of this on the design
- D4.** Apply advanced problem-solving skills, technical knowledge and understanding, to establish rigorous and creative solutions that are fit for purpose for all aspects of the problem including production, operation, maintenance and disposal
- D5.** Plan and manage the design process, including cost drivers, and evaluate outcomes
- D6.** Communicate their work to technical and non-technical audiences.

Economic, Legal, Social, Ethical and Environmental Context

Engineering activity can have impacts on the environment, on commerce, on society and on individuals. Graduates therefore need the skills to manage their activities and to be aware of the various legal and ethical constraints under which they are expected to operate, including:

- S1.** Understanding of the need for a high level of professional and ethical conduct in engineering and a knowledge of professional codes of conduct
- S2.** Knowledge and understanding of the commercial, economic and social context of engineering processes
- S3.** Knowledge and understanding of management techniques, including project management, that may be used to achieve engineering objectives
- S4.** Understanding of the requirement for engineering activities to promote sustainable development and ability to apply quantitative techniques where appropriate
- S5.** Awareness of relevant legal requirements governing engineering activities, including personnel, health and safety, contracts, intellectual property rights, product safety and liability issues
- S6.** Knowledge and understanding of risk issues, including health and safety, environmental and commercial risk, and of risk assessment and risk management techniques.

Engineering Practice

This is the practical application of engineering skills, combining theory and experience, and use of other relevant knowledge and skills. This can include:

- P1.** Understanding of contexts in which engineering knowledge can be applied (e.g., operations and management, application, and development of technology)
- P2.** Knowledge of characteristics of particular materials, equipment, processes, or products
- P3.** Ability to apply relevant practical and laboratory skills

- P4.** Understanding of the use of technical literature and other information sources
- P5.** Knowledge of relevant legal and contractual issues
- P6.** Understanding of appropriate codes of practice and industry standards
- P7.** Awareness of quality issues and their application to continuous improvement
- P8.** Ability to work with technical uncertainty
- P11.** Understanding of, and the ability to work in, different roles within an engineering team.

Additional General Skills

Graduates must have developed transferable skills, additional to those set out in the other learning outcomes, that will be of value in a wide range of situations, including the ability to:

- GT1.** Apply their skills in problem solving, communication, working with others, information retrieval and the effective use of general IT facilities
- GT2.** Plan self-learning and improve performance, as the foundation for lifelong learning/CPD
- GT3.** Monitor and adjust a personal programme of work on an on-going basis
- GT4.** Exercise initiative and personal responsibility, which may be as a team member or leader.

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