Generic Skill Requirements for Engineers in the 21st Century

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Abstract *- The lack of generic skills in engineering graduates in the United Kingdom was recognised as long ago as 1980. Since that date there have been numerous studies and reports written on the subject and a number of initiatives have developed to address the situation. Universities and colleges of higher education are most successful when they concentrate on their traditional activities. More than ever excellence in teaching remains fundamental but degree and other programmes of study need to have integrated within them a number of generic skills which enable prospective employees to develop advanced products and services and provide opportunities for like long learning and continuing professional development. This paper considers the developments that have taken place in recent years and how the challenge for the future has been met by the School of Engineering at the University of Derby.*

The Skills Situation Prior to 1980

Generic skills required by engineers may be increasing in number but although the term generic is the buzzword of the late 1990's such skills have existed in degree, diploma and other programmes of study prior to the 1980's. Many programmes incorporated liberal studies to assist in the development of transferable skills but they were very variable in nature ranging from subjects such as law to the history of engineering and in many cases were not formerly assessed.

Concern was expressed by employers about the utilisation of engineers and Finniston in his report 'Engineering is our Future' [1] found that there was a lack of what are now called generic skills in engineering graduates. There were other concerns such as the inability to apply knowledge in the solution of engineering problems due to the theoretical nature of programmes of study, poor level of attainment on entry to higher level programmes in subjects such as mathematics, physics and science and the absence of relevant training by employers. Finniston talked about the 'formation' of an engineer which included the introduction of three levels, an appropriate blend of theory, application and experience, and changes to the educational elements. This latter point brought about the introduction of Engineering Applications as a theme which would place more emphasis on engineering practice and less on advanced engineering theory.

Engineering Applications EA is divided into four elements EA1, EA2, EA3 and EA4. The first two elements are developed during the academic study period and integrated into the programme of study. EA1 includes safety; current regulations and legislation; use of software and physical tools; interpretation of engineering drawings and making measurements etc. EA2 concentrates on the application of scientific and engineering principles to the solution of practical problems of engineering systems and processes. The latter two are developed in the work place under continuing professional development.

Both EA1 and EA2 provide a vehicle for demonstrating generic skills, not only due to the nature of the work but because the most likely method of assessment is by coursework assignments and project work.

The ensuing problems in the late 1980's and 1990's

Transferable skills form an important part of the generic skill set required by an engineer today. Core Skills, Common skills and more recently key Skills have all been used to describe transferable skills. The first widespread use in higher education in the UK was when the former Business and Technician education Council (BTEC) introduced Common Skills into their higher national programmes in 1986. However, universities did not follow suite and it is only very recently that such skills have found their way into degree programmes.

During the late 1980's and continuing into the 1990's the UK faced increased global competition particularly in commercial and industrial markets. The UK has always been strong in invention but in order to maintain a competitive position in world markets in the years ahead it needs to be strong across all sectors of engineering from research and development with innovation in production and marketing. A variety as well as an increase in the number of skills will be required for the future. While an engineering team in the UK might typically comprise largely of engineering graduates with a small number of technicians the equivalent in many other industrialised countries would typically compromise a more balanced and integrated mix of engineers and technicians. Dearing [2] in 1996 stated "The

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only strategy for a nation seeking to maintain and enhance a high standard of living lies in concentration on advanced products and services, a high degree of innovation, challenging and constantly improving standards of achievement and competitiveness, based on a highly educated, well trained and adaptable workforce".

There has been increasing evidence to indicate a mismatch between engineering graduates and the job market. Qualifications provide a yardstick on which an employer or customer may depend. Formal academic qualifications and appropriate practical experience have up until recently been the only requirements to gain employment in industry. However, the importance of such qualifications has diminished in recent years. This change has occurred as the ability of the individual to succeed in the commercial world without high levels of formal qualifications has increased. Employers focus increasingly on different methods of assessment of the suitability of a potential employee. They examine, for example, the personal qualities of the candidate, ability to communicate and work in a team. Graduates, diplomats and other personnel are therefore chosen by a combination of their interpersonal skills and formal qualifications. Skills sought today are more generic and therefore there is a need to reshape qualifications to make them more relevant to the requirements of the global commercial and industrial markets.

The 1990's has seen an increasing number of studies and forums looking at what can generally be described as graduate attributes. In this environment the Association of Graduate recruiters in the UK [3] demonstrated alongside achievement in the traditional learning process in higher education that employers are now looking increasingly for graduates who show qualities listed in Fig 1 (a). The Accreditation Board for Engineering and Technology (ABET) in the USA identified in its proposed ABET Engineering Criteria 2000 [4] the attributes of an Engineer as listed in Fig. 1(b).

- Vision
- leadership, self-reliance and flexibility
- initiative and innovation
- communication skills
- problem solving
- foreign language skills
- ability to work in a team
- understanding and ability to quantify risk

Fig. 1 (a) Attributes identified by Association of Graduate Recruiters

Many of the bullet points in Figs. 1(a) and (b) are the same or similar indicating relative commonality in the most desirable skills required by graduates of today. The message is clear and as with the problems experienced prior to 1980 it is role of both educators and trainers to find appropriate solutions. In summary, the report Planning for the 21st Century [5] stated 'Core skills are described as generic skills, abilities and characteristics which are widely held to be important for effective working, training and learning'

- an ability to apply knowledge of mathematics, science and engineering;
- an ability to design and conduct experiments, as well as to analyse and interpret data;
- an ability to design a system, component, or process to meet desired needs;
- an ability to function on multidisciplinary teams;
- an ability to identify, formulate, and solve engineering problems;
- an understanding or professional and ethical responsibility;
- an ability to communicate effectively;
- the broad education necessary to understand the impact of engineering solutions in a global/societal context;
- a recognition of the need for and an ability to engage in lifelong learning;
- a knowledge of contemporary issues; and
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Fig. 1 (b) Attributes identified in the ABET Criteria 2000

Outcomes Approach

Learning outcomes are increasingly being employed in place of learning objectives as the mechanism by which learning achievements are credited. It is possible to place learning outcomes into two broad categories.

(a) Subject related outcomes which are normally developed within the programme modules and are expressed in terms of what the student knows and understands and the technical & professional skills which have been developed.

(b) Generic outcomes and transferable skills which are typically related to personal effectiveness and include for example communication skills, teamwork skills etc.

The number of learning outcomes designated for a module should be small because each statement should describe a learning achievement which is considered fundamental to the purpose of the module. The same is true of the programme generic outcomes. The total number should be manageable but students must be fully aware of the opportunities for achieving both types of outcome. Quite often module outcomes are well defined and documented but

on the other hand generic outcomes often appear as a number of statements in a study programme definitive document. There may be outcomes for each stage or year of the programme therefore defining their level but they may not be traceable to a particular module(s). Engineering programmes by their very nature provide numerous opportunities to develop generic skills however students need to be made aware of them. The underlying principle of learning outcomes is that we focus on what it is that we expect students to achieve. In certain circumstances the use of learning outcomes becomes a mechanical exercise involving little more than a systematic check of boxes. It has to be said that a reductionist tick- box approach is intellectually sterile and that the sensible use of learning outcomes as an integral part of curricular design is highly beneficial to both students and tutors and also makes a contribution to the definition of academic output standards. Angelo [6] stated "it is unnecessary to assess the performance of each student to know engineering graduates from a particular programme are generally developing the attributes of an ideal engineering graduate. Stated another way, we should not confuse the ability of the engineering and education community to articulate a vision for the ideal graduate as a mandate of every engineering programme to demonstrate competence and proficiency in every attribute. Each goal is a yardstick against which to measure programme success, not an item on a check list to inventory failure".

Examples of Common/Key Skills Provision

The BTEC common skills introduced in 1986 proved difficult to operate in practice and further studies indicated a need for revision. In 1991 a new model comprising seven common skills [7] as shown in Fig.2(a) was introduced. There are eighteen skill areas in total and it is a requirement to assess each skill . The scheme is unusual in that the seven skills are graded using the normal BTEC grades of pass, merit and distinction. This fact alone makes the model difficult to operate in practice as it is necessary to firstly grade each of the skill areas in a common skill and then determine an overall grade. The majority of providers of these types of skills use a pass/fail grading which is much easier to administer. There is pressure to replace Common Skills with the more recently devised NCVQ Key Skills however at present they are both available in national certificate and diploma programmes with the former being a mandatory requirement of the awarding body.

The National Council for Vocational Qualifications (NCVQ) introduced, as a result of the increasing evidence pointing to shortcomings in transferable skills, through providers such as Educational Excellence (EdExcel), formerly BTEC, Key Skills in Higher education [8] in 1996. The six key skills are shown in Fig. 2 (b). As expected there is some common ground but interestingly, 'applying design and creativity' is absent in the Key Skills which is surprising as this attribute has been recognised as a weakness in engineers and other disciplines prior to their introduction.

- Managing and developing self
- Working with and relating to others
- Communicating
- Managing tasks and solving problems
- Applying numeracy
- Applying technology
- Applying design and creativity

Fig. 2(a) BTEC Common Skills

- Application of number
- Communication
- Information Technology
- Improving own learning and performance
- Working with others
- Problem solving

Fig. 2(b) NCVQ Key Skills

Like BTEC Common Skills, Key Skills can be achieved at various levels, level 4 being the most appropriate in the case of higher education. However, unlike common skills Key Sills are ungraded i.e pass or fail. One or two universities are now offering key skills as added value to their degree programmes but this is only achieved at a cost. A pilot programme [9] highlights the advantages, disadvantages and complexities encountered during delivery. The advantages are clear in that students gain additional certificates of achievement or may qualify for one of the special wards available for achieving a portfolio of skills. The process is somewhat complex for both students and assessors and leads to a number of disadvantages, for example, to quote from the findings of the pilot scheme "The process is complex and tedious with too much detail involved in collecting evidence, the effort required is disproportionate to the rewards. It focuses more on administration procedures than on adding to the students intellectual and skills base". There are many other disadvantages perhaps the main one being the requirement to train the assessor and internal verifier. The training involves qualifying for an award which is both costly and time consuming.

Key skills implementation is being revised and a new system is due to be implemented for the Autumn of 2000. The new documentation is divided into three parts which are:

Part A : What you need to know – gives essential techniques and knowledge
Part B: What you must do – must be met in full
Part C: Guidance - gives examples of activities and evidence

Proliferation of Competencies

The quality Assurance Agency (QAA) for Higher Education set out a new quality assurance framework [10] in October 1998 which will be developed and implemented in the near future. Programme specifications is one of the four areas to be considered for which a set of guidelines nave been published. [11]. The guidelines specify an outcomes approach and the programme learning outcomes are divided into four areas which are:

- Knowledge and understanding
- Intellectual skills
- Subject-related practical/professional skills
- Key/transferable, personal; and social skills

Outcomes and competencies are being increasingly specified in publications. For example the Engineering Council's Standards and Routes to Registration (SARTOR) 3rd edition 1997 [12] for accredited programmes details competencies required for the three levels of engineers, namely chartered, incorporated and technician.

- Exercise independent technical judgement at an appropriate level.
- Assume responsibility, as an individual or as a member of a team, for the management of resources and/or guidance of technical staff.
- Design, develop, manufacture, commission, operate and maintain products, equipment, processes and services.
- Actively participate in financial, statutory and commercial considerations and in the creation of cost effective systems and procedures.
- Utilise effective communication skills and actively participate in human and industrial relations.
- Make a personal commitment to live by the appropriate code of professional conduct which recognises obligations to society, the profession and the environment.

Fig. 3(a) Competencies of an Incorporated Engineer

Engineering Occupational Standards for higher levels (OSC Eng) [13] published in 1998 also specify their requirements in outcome form.

Fig. 3(a) shows the competencies required of an incorporated engineer whilst Fig. 3 (b) details the seven main competencies considered desirable by the engineering industry. Once again a number of the competencies are common to both tables.

- Develop engineering products
- Produce engineering products
- Install engineering products
- Maintain engineering products
- Improve the quality and safety of engineering products and processes
- Plan and manage engineering projects
- Develop own engineering competence

Fig. 3(b) OSC Eng Occupational Standards

Educators are faced with the problem of satisfying the requirements of the QAA, accreditors, awarding bodies such as BTEC and others with respect to incorporating generic skills into their programmes of study. The possibilities are overwhelming when the ability to resource the requirements is questioned. The complexity of implementing BTEC common skills and NCVQ key skills has been noted and a way forward in which some simplification can be accommodated whilst maintaining the primary requirements is essential for future developments

The Model chosen at Derby

The four categories indicated by the QAA are used and a number of skills assigned to each category. The skill set is made up of competencies stated in SARTOR 97, NVCQ Key Skills, BTEC common skills and OSC Eng skills. The total number of skills is 19 as shown in Fig. 4.

The number of skills is considered manageable however the opinion is expressed that if the number exceeds around 24 then the type of problems experienced implementing NCVQ key skills will result.

Each skill can be demonstrated at one or more levels and therefore it is necessary to map these skills against a module(s) thus identifying the level(s). A section of the map is shown in Figure 5.

The outcomes are demonstrated through items of assessed work, as specific learning outcomes are. Therefore by passing a module, the generic outcome(s) is achieved. There are a number of advantages in employing this approach. The reductionist tick box approach and costly implementation of Key Skills is avoided however a framework will be needed to ensure the skills are being assessed in an appropriate manner. A generic skill is traceable to a module(s) unlike the existing model used at Derby where skills are just listed for each stage of the programme or for the programme overall. Grading problems are avoided since the generic skill(s) is passed where the student is successful in a module. The skill set can be easily modified to accommodate future

trends and is not limited to just transferable skills. Mapping provides the facility to define output standards, a future requirement of the QAA under the heading 'benchmarking'. Some outcomes will be tested at more than one level thus making it much easier to consider if the level is appropriate.

(A) Knowledge and Understanding
1. Develop an understanding of engineering and commercial principles and concepts
2. Maintain and Manage Current technology efficiently
3. Take up a role in society with regard to economic and environment sustainability
4. Practice codes of professional conduct, recognising obligations to society, the profession and the environment
5. Extend specialist knowledge in the application of new technologies
(B) Intellectual (thinking) skills
1. Exercise independent technical judgement at an appropriate level.
2. Design, develop and operate products, equipment, processes and services
3. Actively participate in financial statutory and commercial considerations and the creation of cost effective systems and procedure.
4. Use a range of thought processes to identify problems and formulate a number of possible solutions
(C) Practical Skills
1. Use laboratory scientific equipment and instrumentation competently and safety
2. Observe, record, manipulate and evaluate data
3. Demonstrate the process of experimentation, prototype build and manufacturing
4. Prepare descriptive and interpretive technical reports Demonstrate the use of computer keyboard skills.

(D) Transferable/Key Skills
1. Assume responsibility, as an individual or as a member of a team, for the management of resources and/or guidance of technical staff.
2. Utilise effective communication skills and actively participate in human and industrial relations
3. Utilise Information Technology in the preparation, process and presentation of information.
4. Apply numerical skills in the collection and recording of data, interpretation and presentation of data and the solving of problems.
5. Manage own roles, responsibilities and time in achieving objectives, learning, performance, new and changing situations and contexts.

Fig.4 Generic Outcomes in the Derby Model

All outcomes will have been achieved at the level(s) specified upon successful completion of the programme. The diplomat or graduate will therefore have a template of generic skills which along with the certificate of the award will provide a prospective employer with a greater insight in his/her potential.

Perhaps the biggest challenge is in making students aware of the opportunities for achieving these skills. Whilst they are embedded in assessed work such as assignments there is a tendency to overlook the generic outcome and concentrate on the specific outcome linked to the assignment. Through programme documentation and the tutors input the importance of the generic skills should not be underestimated. Students are often at a complete loss when asked to supply evidence of specific skills on an application form or at an interview. The ability to market these skills is increasingly important in our competitive world and the inclusion of careers education [14] in the curriculum can address this problem. The School of Engineering have developed a new module entitled Continuing Professional development in Engineering which includes a section on careers education.

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Module Name	A1	A2	A3	A4	A5	B1	B2	B3	B4	C1	C2	C3	C4	C5	D1	D2	D3	D4	D5
Electrical & Electronic Prin. & Theory	•					•			•	•	•	•					•	•	•
Communication Technology	•			•	•			•			•		•			•		•	
Electrical Measurement & Testing	•	•					•			•	•	•						•	•
IT & ECAD	•			•	•				•		•	•		•			•		•

Fig.5 Section of Skills Set Map