The Universe of Engineering

A UK Perspective

A report prepared by a joint Royal Academy of Engineering/
Engineering Council Working Group, under the chairmanship of
Sir Robert Malpas CBE FREng

Attachments

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Preface

In late 1999 the Science Minister, Lord Sainsbury of Turville HonFREng, invited the Chairman of the Senate of the Engineering Council Dr Robert Hawley CBE FREng FRSE "to review the contribution the Council should make to add value to the engineering community, to the benefit of the UK economy". The Hawley Review Group is addressing this task.

The Hawley Review is based on the premise that the engineering community extends well beyond the commonly recognised boundaries of the profession. It followed that the review would need to explore and define the wider engineering community as a foundation for its further work. For this purpose a joint working group was set up with members nominated by The Royal Academy of Engineering and the Engineering Council reporting in the first instance to the President and the Chairman of those two bodies. Sir Robert Malpas CBE FREng was invited to chair the working group.

The terms of reference are given at Attachment A.

The Working Group comprised five experienced engineers, two each nominated by The Royal Academy of Engineering and the Engineering Council and a chairman, as shown below. Secretariat support was provided by The Academy.

Chairman: **Sir Robert Malpas CBE FREng**

Nominated by the Engineering Council:

Professor Peter Hills CEng	President, Institution of Engineering Designers; Visiting Professor at Brunel University; Visiting Fellow of University of Newcastle
Professor Tony Ridley CBE FREng	Professor (Emeritus), Imperial College

Nominated by The Royal Academy of Engineering:

Dr David Grant CBE FREng	Technical Director, Marconi plc
Professor Ian Shanks FREng FRS	Science Advisor, Unilever Research

The Working Group secretary was Mr Brian Doble, supported by Ms Jennifer Gristock. Additional support was provided by Mr Keith Davis, Head of Engineering Affairs within The Academy.

The Working Group met four times with considerable interchange of views and drafts by e-mail. A note summarising the main points that emerged from the first meeting was used as the basis of discussion, separately, with three engineering professors, one Vice-Chancellor (an engineer), all four in their personal capacity; eight Engineering Institutions, two scientific societies, the Royal Society, the British Council, and the Engineering Council. Discussions were held with the Director General Research Councils. The views of business and industry were represented by the members of the Working Group.

The term "the engineering profession" is used in this report to mean the people, organisations and activity encompassed by: the Engineering Council, the Engineering Institutions, Engineering Faculties (those with engineering in their title) of Universities and Further Education Establishments, and The Royal Academy of Engineering. The report is directed initially to the engineering profession with an eye on the possibility that parts or all of it may be given wider distribution, for example to the wider engineering community, and to government, amongst others. If so it will have to be shortened and edited as appropriate.

Glossary of Terms

Fuller definitions and elaboration of the principal terms used in this report are given in Attachment B "Definitions" and Attachment C "Characteristics of Engineering".

Science is the body of, and quest for, fundamental knowledge and understanding of all things natural and man-made; their structure, properties, and how they behave.
Pure Science is concerned with extending this knowledge for its own sake.
Applied Science extends this knowledge for a specific purpose.

Engineering is the knowledge required, and the process applied, to conceive, design, make, build, operate, sustain, recycle or retire, something with significant technical content for a specified purpose: a concept, a model, a product, a device, a process, a system, a service, a technology.

The *"knowledge required"* is the growing body of facts, experience and skills in science, engineering, and technology disciplines; coupled to an understanding of the fields of application.
Engineering Knowledge is the *"know-what"*.

The *"process applied"* is the creative process which applies knowledge and experience to seek one or more technical solutions to meet a requirement, solve a problem, then exercise informed judgement to implement the one that best meets constraints.
Engineering Process is the *"know-how"*.

Technology is an *enabling package* of knowledge, devices, systems, processes and other technologies, created for a specific purpose. The word technology is used colloquially to describe either a complete system, a capability, or a specific device.

Innovation is the successful introduction of something new. In the context of the economy it relates to something of practical use that has significant technical content and achieves commercial success. In the context of society it relates to improvements in the quality of life. Innovation may be wholly new, such as the first cellular telephone, or a significantly better version of something that already exists.

The Universe of Engineering is used to describe the range of activities in which engineering is involved.

The **Wider Engineering Community** is used to describe the very many people; engineers, scientists, metallurgists, programmers, and many others, who practise engineering in one form or another, to a greater or lesser degree, in the course of their professional activities.

Executive Summary

The central role of engineering in society and the economy is not evident to the public at large nor to the media in particular; the popular perception being generally confined to manufacturing and major building works. The engineering profession is considered by many, including unfortunately many young, as a somewhat dull, uncreative, activity wholly associated with the so-called "old economy".

This report seeks to illuminate the main issues at the heart of this unsatisfactory situation and makes suggestions as to how they might be tackled. It will provide a background for the work of the Hawley Group set up expressly to identify and deal with those issues that are the concern of the Engineering Council. It will also be relevant to many others who are actively working to ensure the nation's future supply of high quality practitioners of engineering and their effective use, such as: the Engineering Institutions, academia, government, business, The Royal Academy of Engineering, and the Campaign to Promote Engineering.

The **universe of engineering** is much larger than generally supposed. Its size and range can be gauged by the following facts:

- At least half of the 1500 companies (other than purely financial) quoted daily in the Financial Times depend on engineering to be competitive, and so survive and prosper.

- One or more, in some cases all, the engineering disciplines are involved to a significant degree in eleven substantial "application" fields that categorise the economy. This is shown as a matrix in section three of the report.

- The so-called "new economy" was created, and continues to be created, through the process of engineering.

- Economists have added *technology* to the traditional three prime inputs to all economic activity, *labour, capital, materials*. It is the engineering process which creates technology.

For the role of engineering to be properly understood and recognised it is necessary to know what it is, and particularly how *science, engineering,* and *technology* relate to each other. The report explores this at considerable length, because of its importance, offering definitions and descriptions for adoption by the profession and by the science community. Until this happens, the public, if not the practitioners, will remain confused.

Science, engineering, and *technology* are closely interrelated and tend to overlap though each is distinct from the other. Definitions and comments are given in the glossary on the preceding page, in the text of the report, and in attachments B and C.

Engineering has two components, *engineering knowledge*, the "know what", and *engineering process*, the "know how". This unbundling of the word makes it easier to describe engineering more clearly and to relate it to science and technology. For example it enables the point to be made that the teaching and recognition of the engineering process does not figure as highly as it should in academia, nor in the Engineering Institutions.

A better understanding of engineering also makes it evident that "*the wider engineering community*", the people who practise engineering, is larger than generally recognised. It comprises not only those who call themselves engineers, but all those who practise engineering, wittingly or unwittingly, in the course of their professional activities, people who do not necessarily wish to identify themselves with engineering. Reliable data on this wider community is hard to come by. The report recommends that this situation be corrected. Relevant figures are:

- There are about 2,000,000 people in the UK who call themselves engineers. About three quarters of them have a professional engineering qualification.

- There are about 600,000 engineers with qualifications at the Chartered/Incorporated level, some 160,000 of these are registered with the Engineering Council, and can use the titles *chartered/incorporated/technician* engineer as appropriate.

- There are about 620,000 members of the thirty four engineering institutions nominated by the Engineering Council, though this number contains much double counting (members of more than one) and many retirees. The Institutions reckon that there are many more people who would benefit from becoming members of one of the thirty four Institutions.

- There are no reliable figures even to estimate the numbers of people whose title does not include engineer, but who practise engineering in the course of their work, *scientists, technologists, metallurgists, computer programmers*, and many more.

The Engineering Council and the Engineering Institutions are actively pursuing the objective of making themselves relevant to this wider community, not necessarily with the objective that all the people in the wider community should become either registrants of the Engineering Council or members of the Institutions. There is a recognised conflict between setting out to be both *exclusive,* where they set and maintain standards; and *inclusive,* where they aim to have wider appeal.

Academia has created, and is creating, many courses covering widespread activities directed at the modern economy. Many are multidisciplinary. Some avoid having *engineering* in their title, *design* and *technology* being preferred, as by so doing they attract greater numbers, frequently of very high quality. There are some 4000 engineering related courses at universities, higher and further education establishments. There are a further 4000 computer related courses. Of these 8000 or so, some 1200 are accredited by the Institutions on behalf of the Engineering Council. There is an issue that needs to be addressed.

Science and engineering depend on each other – and upon business process skills - for the successful conversion of knowledge and experience into something useful. They need therefore to work more closely together. Suggestions are made to this end.

The public image of engineering in the UK is poor, furthermore visibility of the profession is low and confused, and it is often difficult to gain access to information about the profession. Suggestions are made to address this unsatisfactory situation. Central to all of them is gaining widespread understanding and recognition of the relationship between science, engineering, and technology.

The Working Group urges the leaders of the engineering profession, along with leaders of the scientific community, and with the collaboration of government, actively to address the issues raised in the report. It may require mechanisms additional to those existing at present.

1. Introduction

During the course of the 20th century, engineering has moved from a relatively small number of clearly defined disciplines to a vastly greater diversity of activities, including the burgeoning areas of telecommunications and information systems. Furthermore engineering is increasingly being practised in a variety of professions and organisations which are not normally associated with engineering. Add to this the fact that technology, which is created through the process of engineering, is now recognised by government and corporations as the main driving force for profitable growth and to sustain developed societies, it becomes evident that engineering permeates society and the economy. It is worthy of note that economists have added *technology* to *labour, capital* and *materials*, as the fundamental inputs to an economy. Robert Solow, an American economist, was awarded a Nobel Prize in the 1950's for this revelation.

The role and benefits of engineering to society and in the economy is not evident to the public at large, who tend to confine engineering to manufacturing and major building works, seeing it as a dull, uncreative, profession wholly associated with the so-called "old economy". The word engineering tends to be lost somewhere between science and technology.

This report seeks to illuminate some of the issues at the heart of this unsatisfactory situation and makes suggestions as to how they might be tackled. It does so aware that most, if not all, of them are being actively addressed by the Engineering Council, the Engineering Institutions, The Royal Academy of Engineering and by academia.

2. Engineering

For engineering to be more widely understood it is first necessary that it should have a generally accepted definition within the profession, more comprehensive than exists at present, it is also necessary that there be a consistent articulation by the profession of the relationship between *engineering, science, technology* and *innovation* which can become widely accepted by those who are directly involved in them.

That it took much effort by the five experienced engineers of the Working Group to do this to their satisfaction makes it not surprising that the public at large has difficulty with the word "engineering". It manifests the need for a definition that is comprehensive, that can stand the test of time, and that can and should be broadcast on every possible occasion.

Attachment B is the Working Group's suggested definitions. No doubt they can be further refined. Tested so far, they have been well received by the profession, particularly describing engineering as having two distinct components, engineering knowledge - the *"know-what",* and engineering process - the *"know-how"*. The definitions are further developed in Attachment C - Characteristics of Engineering.

The Working Group draws attention to the following points that arose in discussion about the engineering process.

- It is the process of engineering in particular which is practised by a much wider community than that encompassed by the engineering profession, whether or not the practitioners are engineers, or recognise explicitly that they are so doing. For example, the scientist converting knowledge into something of practical use such as a technology, the computer expert devising new software and hardware, the instrument maker designing a new or better instrument, are all engaged in the process of engineering.

- Engineering process, though as important as engineering knowledge, some would say more so, does not figure as prominently within the profession, neither in the Institutions nor in academia. It should do so. Some steps are being taken by academia and the Engineering Institutions in this direction.

- Teaching engineering process, which involves practice and experience, is not easy, nor can much of it be readily represented by formal mathematics. For these reasons and perhaps because in some academic quarters much of it is not regarded as scholarship – at least not by those who regard scholarship as a rigorous science based quest for new knowledge and understanding - it does not rank as highly as engineering knowledge. However in some courses, for example engineering design and product design, it is possible to ensure that it permeates the whole course.

- There is a need to define the knowledge, skills, activities and experience that constitute the engineering process, particularly so that they can be taught as transferable modules, for example, courses in project management. These should be readily available to others - non-engineers - who engage in the conversion of knowledge and experience into something useful.

- It needs to be more widely understood that it is the engineering process which has led to and continues to create the modern economy. It is the engineering process which is converting the "new knowledge" of science and engineering into new computer software and hardware, mobile telephones that can link to the internet, digital television, medical implants, new drugs, pharmaceuticals, machines which can learn, etc.

- It needs to be made evident to the public that engineering, practised as a process, is a hugely creative activity.

- The verb "to engineer" exists only in English language (to our knowledge). Full use should be made of it. A dictionary definition: "To make things happen, with more or less subtlety" captures it well!

- It needs to be recognised that not all who practise engineering perceive themselves as engineers. Such people generally do not wish to be called engineers, nor do they regard belonging to an Engineering Institution as relevant.

- Engineering is carried out not only by individuals, as tends to be the implication when talking or writing about the subject, but by whole organisations. Indeed, this is the case more often than not, as one person rarely has the full set of knowledge and skills to realise the specified objective. *Concurrent engineering* is a technique used in industry to bring non-engineering specialists into the engineering process.

- Organisations undertaking engineering go well beyond those classified as "engineering" by the stock market, beyond manufacturing, industry and construction. They include, for example, pharmaceuticals, transport, oil and gas, chemicals, etc. Half of the 1500 or so companies (excluding the purely investment companies) quoted in the stock market pages of the Financial Times depend extensively on engineering for the creation, design, manufacture, distribution, and marketing, of their products, devices, systems, processes. A list of these is given in Attachment D. The extent of the universe of engineering is described more fully in the next section of this report.

- The profession has to redouble its efforts to change the way influential organisations, such as government departments and the media, talk and write about engineering.

Science engineering and *technology* are very closely linked and interrelated. However, there are several important points which distinguish engineering from science, and technology, and innovation, made evident by the definitions. These points should be brought out as often and as widely as possible by the profession, not to separate engineering from science and technology but, on the contrary, to ensure that the central role of all three in so much of human endeavour, is fully understood.

- Engineering and technology are not synonymous. It is the process of engineering which creates technology and uses technology to do many other things, including creating new or improved technology.

- The engineering process converts scientific, engineering and other knowledge and experience into something useful, so although science and engineering are intertwined, engineering is not a subset of science.

- The engineering process has two crucially important bridging roles, between science and technology, and between technology and innovation. Excellent illustrations of these bridging roles, and of the close interplay between science, engineering, technology and innovation, are given in a letter from Sir David Davies CBE FREng FRS to the Science Minister - Attachment E.

- It is a feature of engineering that it deliberately "engineers out" its visibility through continuous improvement and simplification of its creations. For many years motor cars required the weekly ministrations of a competent technician. Computers when first invented had to be operated by people skilled in the technology. Aeroplanes until relatively recently were required to have a qualified engineer in the crew. Thus engineers having done their job well disappear from public association with their own creations. What remains prominent in the public mind is the truly wondrous technology. This feature of engineering adds to the problem of public recognition.

Comments on Research

Industry in the UK requires a substantial national engineering research infrastructure. This is largely based in universities and much of the longer-term research is financially supported by EPSRC. In 1999/2000 EPSRC's annual budget for new engineering research programmes was £88 million. Matching funds are generally made available from industry.

An important trend in engineering research is the growing number of interdisciplinary programmes that not only incorporate different technical disciplines but also involve social and economic research. The Innovative Manufacturing Initiative (IMI), for example, is a £10 million per annum programme managed by EPSRC, ESRC, BBSRC, and involves DTI and DETR. The objective of IMI is to link excellent engineering research with excellent organisational and social research, and also have industrial partners, so that the resultant research has business and economic relevance.

The term "Technology Research" is becoming a recognised activity alongside scientific and engineering research. Technology research increases the UK's capability to create *enabling packages* of technology that are exploited through an engineering process. The difference between *engineering research* and *technology research* is small but crucial. Engineering research generally places greater emphasis on process (such as design and manufacturing methods) whereas technology research often places a greater emphasis on technical content (such as device characteristics). These two forms of research are complementary. Sadly there are too many national examples of excellent technology research that fail to gain economic benefits due to inadequate attention to engineering or business processes.

3. The Universe of Engineering

The title was chosen because it reflects the huge and growing extent of activities in which engineering is practised by engineers and many others both within and without the profession; and its continuing expansion into new fields of activity. The use of "Boundaries" to describe this was thought to be too confining. Similarly "New Horizons" assumes that the present scope of engineering is well known, which it isn't.

The present scope of the engineering profession is very much greater than is generally recognised. A scan of university courses, the UCAS list, and the activities embraced by the professional Engineering Institutions, manifests its breadth and depth, that it is expanding with the times, and that it is at the forefront of the modern economy. This is not widely recognised, nor is the extent to which engineering is practised outside the profession.

To capture the extent of the universe of engineering, a pictorial representation in the form of a matrix is shown and described in the following pages.

The Engineering Universe

The "engineering universe" includes many new and emerging fields of engineering within a huge landscape of mature or widely understood engineering domains. An attempt has been made to describe succinctly the "universe" so that most of the mature and emerging fields can be seen. With additional time and effort it would be possible to quantify the size and economic significance of all fields.

A pictorial representation of the "universe" was developed after reviewing three key reasons for the emergence of new engineering fields. In the first case, new fields are created by the redirection of a mature engineering skill to a novel field of application. For example, reapplying the physical processes of nanotechnology from the field of electronic devices into the development of instruments for minimally invasive surgery. In a second case, new fields involve an innovative set of engineering skills to apply novel technology or science-based knowledge effectively. An example is the development of bio-engineering processes to grow and apply tissues. A third source of new engineering is in the application of improved engineering processes, tools, resources or managerial and organisational competencies. For example, the ability to distribute engineering tasks on an Internet-enabled global product development project.

It is important to note that the longer established engineering disciplines are changing in scope. For example, civil engineering now includes the practice of improving and maintaining the built and natural environment.

In principle it might be convenient to outline pictorially a universe in a cube that has three axes. The first axis would describe fields of *application,* the second would describe engineering or scientific *disciplines,* and the third would include aspects of applied engineering *processes*, knowledge and management. The cube can be considered to represent where engineering is applied, what disciplines are involved and how it is practised. To simplify the presentation, only the first two axes have been described and illustrated in this note.

Although the third axis of this universe model will not be shown in detail, it is worth noting briefly some of its key attributes. It was found helpful to relate the third axis to the engineering lifecycle and describe it as a number of stages. Some stages are sequential and some are concurrent. These stages, or processes, typically start with requirements analysis and engineering product or system conception; this is supported by economic analysis and development stages, then manufacturing and construction stages through to operation and service stages and finally into the recycling, replacement or retirement processes.

All of these stages involve creative, organisational, managerial and business competencies, and are frequently set in a competitive and increasingly international business environment. Many of the third axis process and knowledge competencies are generic to the wide range of engineering applications and disciplines. Thus, for example, the managerial skills gained in one mature field of engineering may prove very beneficial to the skills needed in an emerging field.

As stated above, the pictorial representation in this report has concentrated on *applications* and *disciplines*. Eleven very broad engineering application fields were chosen, and the choice was informed by reference to economic and social segmentation used in the UK Foresight studies.

Eleven *discipline* fields were chosen, five of these are broad underpinning areas often referred to as science disciplines. They are shown here to acknowledge the fact that engineering processes feed from the scientific rigour of established subject areas, though engineering usually employs a knowledge base that is far wider than any single science discipline.

The diagram clearly shows that the disciplines needed to address a particular engineering application frequently comprise a number of specialist engineering and scientific disciplines jointly focussed on the requirement or problem. Boxes in the diagram containing dots indicate areas of significant activity. However, the level of activity - for example, the number of engineers - varies considerably across the "universe". Consequently the dots are not equally weighted.

Some of the more important information shown in the diagram includes:
- the emerging engineering fields in healthcare and bio-engineering
- the wide influence of materials skills
- the wide influence of electronics and IT.

The Universe of Engineering Matrix **Figure 1**

APPLICATIONS \ DISCIPLINES	Mathematics	Physics	Chemistry	Bio-sciences	Materials Science	Civil Engineering incl. Structural & Building Svs.	Mechanical Engineering & Aearospace, Marine & Agriculture	Electrical Engineering incl. Power Gen. & Power Trans.	Chemical Engineering & Mining & Oil/Gas/Nuc.	Electronics Engineering incl. Computing, Comms /Control also IT field (& Software)	Medical Engineering & Bio-Engineering
Healthcare & Social	●	●	●	●	●		●		●	●	●
Leisure & Entertainment	●	●	●		●	●	●			●	
Education	●				●					●	
Commerce, Trade & Finance	●									●	
Communications & IT	●	●								●	
Defence & Security	●	●	●	●	●	●	●			●	
Transport	●	●	●		●		●	●		●	
Agriculture & Food	●		●	●	●		●		●		●
Engineered Materials	●	●	●	●	●	●	●		●	●	●
Energy & Natural Resources	●	●	●	●	●		●	●	●	●	●
Built Environment	●	●	●	●	●	●	●	●		●	

<u>Note</u>
To simplify the presentation of engineering *applications* and *disciplines,* the content and description of individual fields is not comprehensive. Similarly, the presence or absence of a "dot" is not based on a quantitative analysis. A more detailed representation is possible, with indications of strengths of interactions. This diagram is intended to give a broad view.

Definitions of the *applications* and *disciplines* displayed in the above matrix follow in the next two pages.

APPLICATIONS

Healthcare and Social
Services and products to improve the quality-of-life of individuals and groups in society. This includes medical and pharmaceutical systems, supplies and services.

Leisure and Entertainment
Services and products for entertainment, cultural, social and sporting pursuits.

Education
Services and products for school, college and university-based education together with distance-learning, vocational and lifelong learning.

Commerce, Trade and Finance
All systems and services for the local and international trade in goods and finance. This includes the retail trade, distribution, banking, insurance services and electronic commerce.

Communications and IT
The creation, processing, management and distribution, of information by physical media and by broadcast and by communications network. Voice, video and information transmission systems using satellite, radio and cable.

Defence and Security
Systems, services and products for the provision of national defence and security on a world-wide scale. Civil security and emergency services. Private and commercial security services and products.

Transport
The mobile, but not the built, element of transport networks together with the supporting fixed installations. Transport includes personal, commercial and public vehicles for air, sea and land.

Agriculture and Food
Farms, process plant and services for livestock, crops and other natural or synthetic ingredients that are processed into food and drink.

Engineered Materials
Process plant and services developing and producing materials such as plastics for direct application or further processing into products and systems. The field includes advanced materials for pharmaceutical, human implants, electronic/photonic, aerospace and similar demanding applications.

Energy and Natural Resources
Plant, systems and services for:
- the generation and distribution of electrical energy, oil gas and other fuels
- acquiring, processing and distributing water and liquid wastes
- acquiring, pocessing and distributing minerals and raw materials.

Build Environment
All civil construction, planning and services including private, public and commercial buildings, factories, road and rail networks, harbours, waterways, airports and public spaces.

DISCIPLINES

Mathematics, Physics, Chemistry, Bio-sciences and Materials Science
The fundamental studies, knowledge and understanding of disciplines in applied mathematics and applies science.

Civil Engineering including Structural Engineering and Building Services
The engineering disciplines associated with the creation, improvement and maintenance of both the built and natural environment.

Mechanical Engineering and Aerospace, Marine and Agricultural Engineering
The engineering disciplines associated with machines and motion.

Electrical Engineering inluding Power Generation and Transmission
The engineering disciplines associated with the generation, transmission, distribution and application of electrical power.

Chemical Engineering and Mining, Oil, Gas and Nuclear Engineering
The engineering disciplines associated with the process of natural and synthetic materials, liquids and gasses.

Electonics Engineering including Communications, Computing and Control Engineering and the field of IT.
The hardware and software engineering disciplines associated with electonics, photonics, and their application in fields such as communications, computing and control. The disiplines associated with Information Technology including the collection, processing and distribution of information.

Medical Engineering and Bio-Engineering
The disciplines involved in developing products and systems to diagnose, monitor support and treat patients.

Other Indicators of the extent of the Universe

That the universe of engineering is much larger than manufacturing and major building projects, as is often implied, is evident from the following facts:

- Some 50% of the companies whose shares are quoted daily in the Financial Times are dependent on engineering to create, design, and operate their products and services, their manufacturing processes, packaging and distribution, to mention only some of their activities.

- There are about 160,000 engineers registered with the Engineering Council working in the UK, mostly chartered and incorporated, some technicians, out of a total of about 570,000 graduate engineers working in the UK. (Labour Force Survey 1997/8). It is estimated that there are about 1,500,000 other engineers, (Labour Force Survey 1997/8) such as precision instrument makers, factory inspectors, motor mechanics, heating engineers, computer analysts and programmers, of whom, it is guessed, about two thirds will have a qualification relevant to their profession. Data on this is hard to come by and should be improved.

- Without considerable research it is impossible to estimate the number of people who, in the course of their work, practise engineering. The number is large.

- There are about 4000 undergraduate courses at universities, higher education establishments, appearing in the "Engineering Courses" handbook by UCAS including for example "Audio Technology and Imaging Science", "Computing and Music Technology", "Design Technology and Business".
  There are a further 4000, or so courses on computer science which involve engineering to some degree.
  There are about 1200 courses accredited by the Engineering Institutions.

4. The Practising Population, Qualifications, Accreditation

The Working group were asked to define the practising population of the universe of engineering, the "wider engineering community".

This is a difficult area to deal with since it involves a range of differing qualifications required by the specialist professional Institutions; a substantial number of people who practise engineering but are not perceived as engineers, and many people who are commonly termed engineers but are not engineers by any definitions given in this report.

The subject leads immediately into issues such as accreditation of engineering courses and qualifications for membership of institutions, subjects which are complex and beyond the competence of the Working Group to resolve. There is also the problem that the available statistics use different classifications and are difficult to analyse. The leaders of the engineering profession need to improve and collate these statistics, and the relevant government departments and other repositories of data on the profession should ensure that their statistics are coherently classified and relevant to the modern era.

The main points that arose from discussion with relevant bodies on the practising population, qualifications and accreditation are:

- The profession and activity of engineering should set out to be made attractive to the widest possible range of people. Not only is there a very wide range of professionally recognised engineering to offer, from medical engineering to racing car engineering, telecommunications, computer hardware and software, but also a wide variety of activities such as research, conceptual engineering, design, project management, manufacturing, building, operating, maintaining. There are also several levels of qualification all offering rewarding, fulfilling careers; the highly qualified postgraduate engineer, chartered, incorporated or technician engineer.

- There would appear to be four categories of people populating the universe of engineering:
  1. Chartered, Incorporated, Technician, engineers registered with the Engineering Council.
  2. Engineers who are members of Engineering Institutions. This is a broader group than those who are registered with the Engineering Council, which it intends to grow.
  3. Those practising engineering calling themselves engineers, who are not members of an Engineering Institution.
  4. Those who practise engineering in pursuit of another profession who do not consider themselves, or perhaps do not wish to be identified as, engineers.

- There are precise figures available for those who are affiliated to the Engineering Council at work in the UK. In round terms, they are, at the present time;

Chartered Engineers	115,000
Incorporated Engineers	34,000
Technician Engineers	11,000
Total	160,000

- The membership of Engineering Institutions is believed to be approximately 620,000, though this number includes an unquantified number of dual (or more) memberships, and many who are retired. The Engineering Institutions reckon that there are at least twice this number of people who would qualify for Institution membership, though they would not necessarily set out to attract them to become members. Many are working towards making themselves relevant to the wider engineering community.

- No clear, reliable statistics are available for the number of people with engineering qualifications who do not meet those required by the Engineering Council/ Engineering Institutions. They are not readily evident from current statistics, but are estimated to be about 1,000,000, there being an estimated further 500,000 people practising engineering with no qualifications.

- The number of UK resident students graduating at all levels from engineering and technology courses in 1997/8 was 16,200, with computer science graduates amounting to a further 9,500 (HESA 1999). Many take their skills into other professions with good effect.

- It is difficult to estimate reliably the number of people who practise engineering as part of another profession, people who do not call themselves engineers, nor probably consider that part of what they are doing is engineering. This group is however very large comprising among others:
  - Chemists, physicists, biologists, computer scientists, metallurgists, mathematicians, others, working as individuals or in teams, to produce say, a new or better, product, device, manufacturing process, a system, or a technology.
  - People of many disciplines producing computer software.
  - People of many disciplines operating and sustaining complex manufacturing processes of all kinds, small and large.
  - Set designers for the performing arts who harness and synchronise many technologies to produce dramatic visual, sound and lighting effects.
  - Designers of musical instruments, especially those with significant electronic content.

  And so on, the list is long. The capability of these people, who work with others of many disciplines including qualified engineers of all levels, could be enhanced by taking modular courses on the transferable skills of the engineering process.

- It is recommended that the Engineering Council together with the DTI, the CBI and the EEF, seek to identify, where possible, the wider community practising engineering, not only because this is important information to be kept up to date, but because the Council should keep under constant review how it relates to this wider group.

- The Institutions should collectively, relate to the full spectrum of engineering activity. They should represent the whole profession. Many do. Some however are perceived to exist only for the highly specialised and qualified, their terminology accentuating exclusion of others. The objective should not be to try to bring everyone in this wider community who practises engineering into membership of some form, but to identify who they are and what they do, by so doing determine how to relate to them. They might offer help and advice, and point to professional development courses available to improve skills and qualifications, courses which can be taken without necessarily having to become an Engineering Council registrant.

- Accreditation of HEI and Further Education courses is seen, rightly or wrongly, as a constraint to recognition of the newer activities in the universe of engineering, particularly those of a multidisciplinary nature. This is a major issue which needs to be addressed by the profession. No doubt it has high priority in the objectives of the Hawley Group's work.

- There would appear to be some conflict between:
  - Maintaining standards.
  - Attracting students to more modern, multidisciplinary, courses which reflect the evolving nature of the economy.
  - Broadening the membership of the Engineering Institutions.
  - Licensing. The number of activities requiring demonstration to an external regulating agency that an employee has the requisite skills and competencies to perform tasks is increasing. Such agencies require to be satisfied with the competence and qualifications of those who carry out the work under licence.

  Several Institutions are tackling this issue radically, for example by having, or seeking to have, only one class of membership regardless of the qualification. One Institution describes the issue of trying to be both *exclusive,* to maintain standards, and *inclusive,* for wider appeal. They are not helped trying to implement this change by the Privy Council who require that the same structure be adopted by all Institutions simultaneously, which means that progress will be made at the pace of the slowest.

5. More Effective Links between Science and Engineering

All technologies, devices, products, processes and systems with significant technical content, are created by the process of engineering to meet a specified objective, whether it be done by engineers, scientists, or by others. Relevant experience and knowledge from scientific, engineering and managerial domains support the engineering process.

Extending the boundaries of knowledge, illuminating areas of ignorance, is the domain of science. It is often at the interface of science and engineering that important and exploitable discoveries are made. Science and engineering are thus the major constituents of all existing and future technologies, whether the science precedes the engineering, is discovered during the engineering process, or follows it.

There is "Science led Technology" where, for example, the science of semi-conductors has led to the modern electronic age, and "Technology led Science", where thermodynamics followed the invention of the steam engine.

The close interrelationship between science and engineering is well illustrated in the examples given by Sir David Davies in a letter to Lord Sainsbury, Attachment E.

It follows therefore that engineers and scientists should work together closely to exploit to the full the innovative potential released by scientific research. This, of course, does happen, but needs to be stimulated. Some proposals for this are:

- Make the capability of dialogue between engineering and science a required skill for those seeking qualification in the engineering process. Teach engineers both at university and in subsequent formation how to step in to the world of science, to seek greater fundamental knowledge of the activity in which they are engaged, and to be aware of the new horizons that may become relevant to their interests.

- Similarly, suggest to the relevant authorities that scientists, particularly those who wish to commercialise their work, learn how to relate to the worlds of engineering and business.

- There are techniques to develop fruitful dialogue between engineers and scientists, dialogue which goes beyond the frequent sterile exchange "what do you have to offer that may be of interest". Existing techniques for fruitful dialogue need to be extended, developed and taught.

- Impress upon business managers and engineers that it is those enterprises with profound knowledge of their markets, products, and the processes by which they are made, that will succeed. Profound knowledge is required of how the product/process/application works and of its environmental impact in all stages of manufacture, use and disposal. Such knowledge is only obtained by the combined efforts of scientists and engineers engaged from within the company, or commissioned from without. Joint quest for such knowledge, by teams of scientists and engineers generally produces results for immediate implementation, as well as an agenda for further relevant research.
- Encourage dialogue between Engineering Institutions and scientific bodies to determine emerging knowledge and technologies of mutual interest.

- Hold joint meetings, lectures and presentations.

- Encourage greater dialogue between university departments of science and of engineering.

- Encourage in schools at A-levels, the teaching of the relevant science underpinning recognised major engineering and technological achievement. Some of the City of London Livery Companies have developed excellent courses to this end. Engineering Institutions also are in a strong position to create the material needed and to arrange for its informed presentation.

- More lecture series such as the Faraday Lectures directed to sixth formers organised by the IEE need to happen.
- Keep close to the Foresight exercise.

6. Engineering Image, Visibility and Access to Effective Information

The Engineering Profession in the UK is rightly concerned that the public image of engineering is poor. Furthermore, visibility of the profession is low, confusion in the public perception is high, and it is often difficult to access effective information about the profession, its economic and social contribution, and its huge scope - the “universe”.

The profession is actively trying to change this unsatisfactory situation. It is a huge task, requiring considerable effort and innovative approaches.

One of the challenges is the terminology in common use. For example, there is widespread recognition of the need for *technology.* The word is used extensively by the media, by corporations, by government and financial institutions. Furthermore it is *technology* (not *science* nor *engineering*) which has officially been recognised by economists as one of the four principal inputs to economic prosperity, alongside labour, capital and materials.

It is new scientific knowledge which frequently grabs the headlines. Design is mentioned often, though few people associate the word with engineering. The closest they get to it is industrial design.

As stated earlier in the report, it is a feature of engineering that it tends to “engineer out” its own visibility through improvements to products, systems, and services, such that they no longer require expert attention.

Unfortunately, it is often the case that the public’s perception of an engineer is the “service engineer” who fixes problems.

The common use and meaning of terminology changes with time. At present the financial world is narrowing the meaning of the word technology to “technology stocks” which comprise electronics and bio-technology, as though no other endeavour is about technology.

This is the reality of the situation with which the engineering profession has to contend. The way forward, to bring engineering out of the shadow of technology, and to some extent that of science, can only be through greater public understanding of engineering, particularly through the media. Engineering needs to be readily identified with the words design and technology, both of which have high standing in the public’s mind, and with the fact that it has created “the modern economy” and continues to do so. Exhortation simply to refer to engineering more frequently is not sufficient, there needs to be good reason to do so.

Some ways of doing this, to add to the considerable efforts of the profession are suggested:

- Produce a brochure (The Academy, the Council?) explaining, illustrating, setting out attractively, the extent of the universe of engineering, its central role in society, its creation of the new and the more mature economy. Include in it a selection of phrases for the less informed to use linking engineering to science and technology when reporting on successful endeavour, such as:

  " technology/designs created/improved/developed by engineers/engineering".

  " new scientific knowledge/advances which are being/have been engineered into ——— technology"

  " car/bridge/computer/television/mobile phone which has been beautifully designed and engineered by ——"

- Persuade the media to use the words engineer and engineering wherever appropriate. Through greater understanding they may find that appropriate use of the words adds significant meaning to the written or spoken word, giving important information of the "by whom" and "how" of a reported endeavour. This is of such importance to the economy that it might be considered worthwhile setting up a task force, under the aegis of the DTI comprising representatives of the press, radio, television, and the engineering profession, to determine how best it can be achieved.

- Persuade the CBI and the Institute of Directors to do the same, in their publications and presentations.

- Inform and educate government departments to reform radically the narrow way they refer to engineers and engineering.

- Internet web-sites are now the principal mode of access to information, they are also the main vehicle for presentation of organisations, institutions, corporations. It is therefore very important that the constituent bodies of the engineering profession present themselves well on the Internet, especially to attract the young to the profession.
  Current web-sites of the Institutions and most universities leave much to be desired. They tend to be discipline oriented, not helpful to someone wishing to find out about the appropriate courses and qualifications required to become proficient in a specific activity such as, for example, robotics, satellites, engineering for the performing arts, high speed trains, etc. Interest in railways, a revived "modern economy" activity, requires visiting four or five Institution web-sites. Youngsters interests stem more from subject activities than from disciplines so it is important that the web-sites be extensively hyperlinked - especially to web-sites outside the profession which can stimulate interest in the subject activity.

The fundamental question that Institutions should address when designing web-sites is why anyone would wish to visit them. It is important to create many links to other web-sites from which an interest could arise.

- Although *engineering* has a poor image, *technology* and *design* do not. For this reason many universities, particularly the newer ones, are naming courses leaving out the word engineering, using design and technology instead; naming the activity not the discipline. By so doing they are attracting students. Renaming a course "Multi-media Technology and Design" from "Electronic Engineering —" resulted in many more applicants of higher standard. The content of the course remained unchanged.

- The Campaign to Promote Engineering, sponsored by government, business, the Engineering Council, and the Engineering Institutions should be supported and used to the fullest extent possible throughout the country to get its message across to the public.

- The British Council spends some £6m to £7m per annum promoting overseas the UK's science and engineering excellence and creativity. Because British engineering is not attractive to the young, but British entertainment is, they are developing a project "Engineering Entertainment" that links the two. The project has two parts, an exciting and innovative web-site to be launched in early September, and a film and CD-Plus to be developed in the future. The web-site "CultureLab-UK" will have a variety of cultural entry points of interest to youngsters: film, digital, music, design, fashion, life, and future, linking with the science, engineering and technology involved. It will have an information source providing details on the relevant UK courses and research. The next phase of the project will be a short film, an entertaining display of leading edge technology, graphics and music, distributed to cinemas around the world. A CD-Plus handed out free will contain the film, details of the people behind it, samples of software tools and games, and a directory of the relevant UK courses, as well as hyperlinks to the key web- sites.
  This imaginative and excellent project deserves strong support from the engineering profession and business.

- Britain leads the world in the engineering of special effects for the performing arts. Seventy percent of Japanese computer games are designed and programmed within thirty miles of Liverpool. One third of the £8 billion turnover of the computer games industry is generated in the UK. Nevertheless it seems that the considerable engineering activity involved is lowly regarded in some circles.

- Role models are a powerful way to influence the young, their parents, and those who give guidance on careers. The Academy and the Council should actively promote success stories of people with an engineering background, such as those that have appeared recently in the Financial Times. The Royal Academy's quarterly magazine, Ingenia, is about to feature such stories regularly.

- Promote the making of a television series showing the great engineering achievements which have created the "new economy", a series of the quality and interest generated by the current Channel Four series on why the industrial revolution took place in Britain.

7. New Horizons, The Modern Economy

The so-called "Modern Economy" was and continues to be created by engineering. That this is so needs to be more widely known, written and spoken about.

It is also important to make understood that the activities of the so-called "older economy" embrace almost immediately new knowledge and technology as it becomes available which results in further new technology. The two are blended together, particularly to improve productivity. The distinction between new and old is not helpful, nor is the erroneous association of *technology* with the new, and *engineering* with the old.

The new water ring main around London is an outstanding piece of engineering, almost unnoticed, serving the public. It was designed and constructed using the latest available technologies; the water quality it delivers, its control and distribution. Likewise the steel industry has been revitalised through new technology.
Modern air transport depends on air-traffic control systems of the greatest speed and reliability which only the deployment of the latest technology can achieve.

There are hundreds of examples of innovation in the so-called "old economy" underpinned by new technologies. No sector of the economy which provides goods and services at a world class level can survive and prosper without competent engineering skills, using the latest technology and developing some of their own, to sustain the competitiveness of their products, processes and services.

Regarding the new horizons for engineering, scanning the activities of Institutions and University courses, it can be seen that they provide well for subjects related to the modern economy, more so than is given credit to the profession. However, three issues are evident:

- this is not known, particularly to parents whose children might be interested
- many of the courses are not accredited, particularly those involving several disciplines
- their visibility and accessibility is poor, particularly for the young, and for career advisors at schools.

It is, of course, essential that the Engineering Institutions be aware of what is going on at the frontiers of knowledge, the New Horizons. This most are doing, for example through meetings with the Scientific Institutions and Societies, and by participating and keeping alongside the Foresight and similar exercises.

Producing and keeping an up to date list of subjects which are currently considered to be at the frontiers of knowledge, is of doubtful value, as what some consider a new horizon, might be regarded by others as already well established. Nevertheless the Working Group offer the following list.

New Horizons
Active noise control and active vibration control
Adaptive systems and controls, eg Genetic algorithms
Advanced computer technology, eg fault tolerant architectures
Artificial Intelligence and Knowledge-based Systems
Bio-engineering
Biomaterials
Computer-based and networked learning and training systems
Data compression, error recovery and data encoding/security
Data warehouses, search algorithms and knowledge extraction
Diagnostic sensors
Digital broadcast
Digital signal processing
DNA drugs
Electronic Materials, eg III-V compounds like Gallium Nitride
Energy conversion, eg solid polymer electrolyte batteries, fuel-cells
Flat screen displays, eg light-emitting polymers
GPS Navigation and Geographic Information Systems
Handwriting recognition
Home of the future
Imaging, processing and recognition
Integrated transport systems
Language translation – and text analysis for meaning
Laser-based machining and laser-based surgery
Media technology, including engineering for the performing arts
Medical engineering eg Minimally invasive surgery
Micro-Electromechanical Systems (MEMS)
Molecular engineering
Nanotechnology
Personal and mobile communications, eg, 3rd Generations Mobile
Photonics incl. semiconductor lasers, and fibre-optic technologies
Product coding and product tracking, eg radio frequency “RFID”
Robotics
Simulation and dynamic models, eg Computational Fluid Dynamics (CFD)
Software engineering including automatic code generation
Sound and vision integration.
Space engineering
Speech recognition
Stereo-lithography and rapid prototyping technologies
Telecommunications technology for global networking, eg Internet Protocols
Telemedicine
Virtual reality

8. RECOMMENDATIONS

The report is intended more to illuminate the Universe of Engineering and the problems it presents to the profession than to prescribe a set of specific remedies, so it is inappropriate and somewhat tedious to set out a list of recommendations.

Suggestions and recommendations are made throughout the body of the report. The several parts of the engineering profession will each take from it different messages to follow up as appropriate.

The Working Group urge the leaders of the engineering profession, along with leaders of the scientific community, and with the collaboration of government, actively to address the issues raised in the report. It may require mechanisms additional to those existing at present.

Attached Documents

Attachment A

Terms of Reference

Terms of Reference for The Royal Academy/Engineering Council Working Group

THE UNIVERSE OF ENGINEERING

Background
During the course of the 20th century, engineering has moved from a relatively small number of clearly defined disciplines to a vastly greater diversity of activities, including the burgeoning areas of telecommunications and information systems. This has made it much more difficult to define the universe of engineering. Furthermore engineering is increasingly being practised in a variety of professions and organisations which are not normally associated with engineering.

Aim
The aim of the Working Group is to examine the **Universe of Engineering:**
- the current scope of the engineering "profession" as presently understood, where it is heading, what subjects, competencies, and disciplines should now be included.
- the scope of engineering practised in other professions and organisations not classed as engineering, and how the engineering profession should relate to these.

Objectives
The key objectives are
- To seek a definition of the engineering profession, its constituent elements, and its practising population.
- To seek to define engineering competencies, methodologies, and skills used by other professions and organisations and how to recognise and promote these.
- To articulate appropriate terminology to define the full scope of engineering and the activities of those who practise it, both engineers and others.
- To recommend how to integrate science and engineering for more effective exploitation to the betterment of society and the economy.

Composition
The Working Group should comprise two Fellows of the Royal Academy of Engineering and two members of the Engineering Council Senate. It is to be chaired by a fifth member of the Working Group appointed jointly by these two bodies. A Secretary will be provided by the Royal Academy of Engineering.

Guiding Principles
The Working Group should take full account of:
- Any similar studies which have been undertaken by other science and engineering bodies and should seek their views on its work;.
- Academic institutions and other bodies should be consulted where appropriate.
- The current DTI/Engineering Council Working Group on the Council's future role.

Attachment B

Definitions

It is difficult to capture completely the meaning of an activity as broad as engineering; no definition can eliminate overlap with other disciplines. Nevertheless given the prominence and importance of science, engineering, technology, and innovation, it is necessary to have definitions of these words which are widely accepted.
The following, which can be adapted to reflect specific circumstances, are put forward for consideration.

Science is the body of, and quest for, fundamental knowledge and understanding of all things natural and man-made; their structure, properties, and how they behave.
Pure Science is concerned with extending this knowledge for its own sake.
Applied Science extends this knowledge for a specific purpose.

Engineering is the knowledge required, and the process applied, to conceive, design, make, build, operate, sustain, recycle or retire, something of significant technical content for a specified purpose; – a concept, a model, a product, a device, a process, a system, a technology.

Technology is an *enabling package* of knowledge, devices, systems, processes, and other technologies, created for a specific purpose.
The word technology is used colloquially to describe a complete system, a capability, or a specific device.

Innovation is the successful introduction of something new. In the context of the economy it relates to something of practical use that has significant technical content and achieves commercial success. In the context of society it relates to improvements in the quality of life. Innovation may be wholly new, such as the first cellular telephone, or a significantly better version of something that already exists.

Science is the main, rigorous, knowledge and understanding input to **engineering,** and therefore, **technology.**
The Engineer, and others, use **technology** to create something new; a product, a manufacturing process, a system, **a new technology.**

The three activities, **science, engineering, technology,** are closely interrelated, and frequently overlap.

That **Engineering** is described as *"the knowledge required, and the process applied, to conceive, design, ——"* implies two distinct components to engineering, **knowledge**, and **process.**

- **Engineering Knowledge**: is the growing body of facts, experience and skills in science, engineering and technology disciplines; coupled to an understanding of the fields of application.
  It is the *"Know What"*.
  It is mainly "experience-based" knowledge, which is more difficult to describe and communicate than "codified knowledge" because it must be put into the context of an application.
  Engineering knowledge ranges from the more traditional such as civil, mechanical, electrical, chemical, automotive, aeronautical, to the newer such as, electronic, communications, medical, bio-technical. They are being added to regularly. This is further commented on in Attachment C, Characteristics of Engineering.

- **Engineering Process** is the creative process which applies knowledge and experience to seek one or more technical solutions to meet a requirement, solve a problem, then exercise informed judgement to implement the one that best meets constraints.
  It is the *"Know How"*.
  It requires knowledge and understanding of the underlying science, engineering, and constraints, of the context in which it is being practised, and special skills, both taught and gained by experience, to make it happen. It requires the exercise of judgement. These characteristics are further elaborated in Attachment C.
  Engineering Process is practised in all engineering activity, from concept and design, to operation and maintenance, to a greater degree in the former than the latter.

To Engineer is the verb describing this process. It does not exist in other languages. It is defined as "to make things happen", using knowledge and experience. It is a multidisciplinary activity, requiring the capability among other things, to manage people with diverse knowledge and skills. It calls for the capability to choose solutions from imperfect options, to create order out of disorder.

The Engineering Process has two very important **bridging roles:**

- **it is the bridge between** science **and** technology,
- **it is the bridge between** technology **and** innovation.

<u>**Note**</u>

The Engineering Council's current official definition of engineering is given in their publication "**Engineering 2000"**:

"Engineering is the practice of creating and sustaining services, systems, devices, machines, structures, processes and products to improve the quality of life; getting things done effectively and efficiently".

Characteristics of Engineering

Defining the characteristics of engineering is important, among other reasons in order to explain what it is that distinguishes it from other professions.

It should be borne in mind that engineering is practised by individuals, by teams of people and by whole organisations, as determined by the scale of the endeavour and the range of knowledge and skills required.

Engineering is described above as having two distinct components, **engineering knowledge,** and **engineering process.**

A. Engineering Knowledge is the knowledge required to be applied to the engineering process in hand. It is knowledge of the relevant field of activity and the context in which it is to be practised, for example, medicine if designing an anaesthetic machine, or replacement prosthesis; the physics of space for a geo-stationary satellite; the theory of structures for a bridge; thermodynamics for a jet engine. The relevant science has also to be known.

The US National Institute of Health defines **Bioengineering** as:

"Bioengineering integrates physical, chemical, or mathematical sciences and engineering principles for the study of biology, medicine, behaviour, or health. It advances fundamental concepts, creates knowledge for the molecular to the organ systems levels, and develops innovative biologics, materials, processes, implants, devices, and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health."

Engineering is about meeting specific objectives such as those contained within the above definition. To achieve them, or provide the means for others to do so, the engineer will draw on a bank of knowledge comprising the following subjects, among others, (the list is not exhaustive) which typically form the basis of factual knowledge imparted in most engineering teaching.

- **Materials** and their physical, chemical or biological properties
- **Science** and key underlying principles of the engineering discipline
- **Applied Mathematics** relating to the discipline
- **Knowledge** required to meet technical objectives such as motion, flow, transfer, control, support, containment and physical or information processing — but often carried out in, or destined for, an environment with technical, financial or time constraints
- **Design, construction, application, maintenance, disposal,** of engineering products and systems
- **Information** generation, processing and transmission
- **Modelling and simulation**
- **Innovation and research**

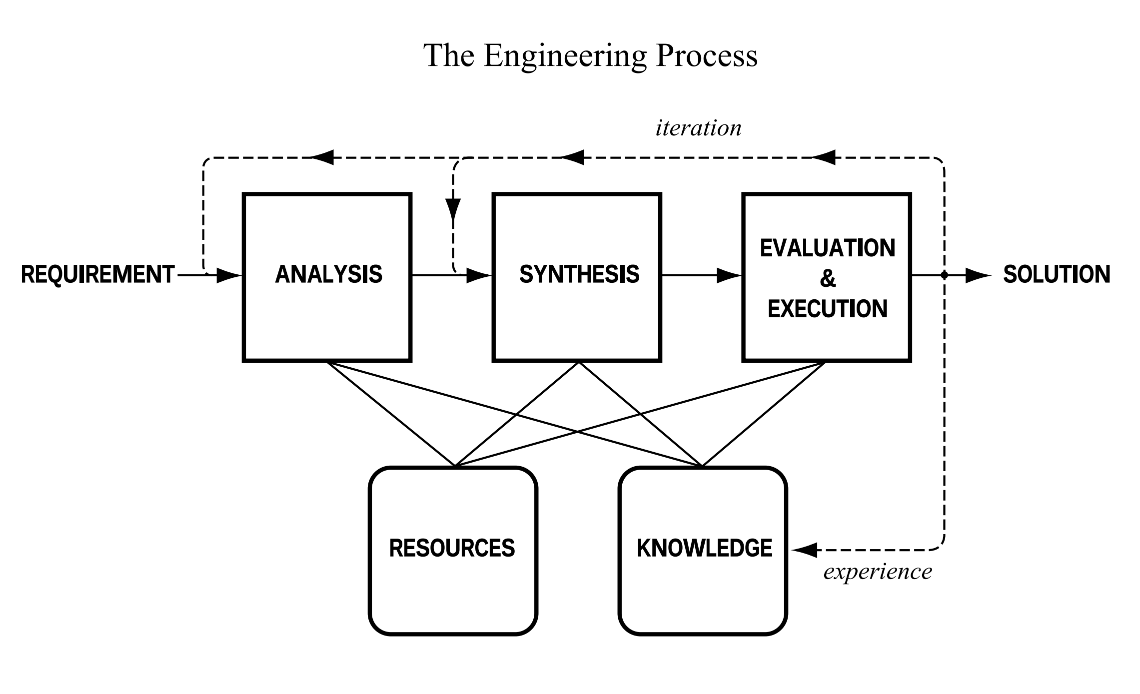
B. Engineering Process assembles all relevant knowledge and experience for a specified purpose.

The Engineering Professors Conference report "Quality in Engineering" produced in July 1989, gives a comprehensive list of engineering processes, comparing them with the corresponding science processes. It is reproduced here in its entirety.

Key Engineering Processes	**Key Scientific Processes**
Invention, design, production.	**Discovery (mainly by controlled experimentation).**
Analysis and synthesis of designs.	**Analysis, generalisation and synthesis of hypothesis.**
Holism, involving the integration of many competing demands, theories, data and ideas.	**Reductionism, involving the isolation and definition of distinct concepts.**
Activities always value-laden.	**Making more or less value-free statements.**
The search for, and theorising about, processes, (eg, control, information, networking).	**The search for and theorising about causes, (eg gravity, electromagnetism).**
Pursuit of sufficient accuracy in modelling to achieve success.	**Pursuit of accuracy in modelling.**
Reaching good *decisions* based on incomplete data and approximate models.	**Drawing correct *conclusions* based on good theories and accurate data.**
Design,construction,test,planning,quality assurance,problem-solving,decision-making,interpersonal,communication skills.	**Experimental and logical skills.**
Trying to ensure, by subsequent action, that even poor decisions turn out to be successful.	**Using predictions that turn out to be incorrect to falsify or improve the theories on which they were based.**

In short, the Engineering Process **is about:**
Analysis
Synthesis
Evaluation
Execution

which can be represented graphically as follows:



The processes of analysis, synthesis, evaluation and execution are generic to many creative and problem-solving activities. The particular attributes that relate this model to an "engineering process" comprise the contents of the knowledge base, the resources, skills and "technical" domains in which the process is applied. An engineering process generally works to meet a requirement within constraints such as time, cost or a performance envelope. These constraints influence each of the four process steps and often require iterative actions to refine a solution.

The **Engineering Process** is about *decisions* and *optimised solutions* as opposed to *conclusions*

Additional to the knowledge and experience required explicitly implied in the above, the **engineering process** requires:

- Knowledge of the relevant constraints, such as economic, social, hazard, environmental, legal.

- Awareness of the interaction with humans, their behaviour, and the human body.

- The ability:
  - to reach into the domains of science, finance, and markets, to seek and apply relevant knowledge and information
  - to manage projects small and large, be it a research, design, start-up, or construction, project
  - to form and lead effectively, multidisciplinary teams
  - to operate in a non-structured environment
  - to manage uncertainty
  - to assess and manage risk
  - to bring to the endeavour an aesthetic sense of shape, form, beauty, as well as functionality.

As the **engineering process** is practised by many outside the engineering profession, modules teaching the transferable skills outlined above are of interest to others to whom they should be made visible and readily available.

It should be noted that engineers and others who are well practised in the skills acquired for the **engineering process,** particularly project management are well equipped and experienced for senior management posts in many fields.

Attachment D

Company Classifications (London Stock Exchange) that depend heavily on Engineering

The following classifications of companies quoted on the London Stock Exchange (excluding the purely investment companies) represent about half the total of companies listed.

They depend heavily on engineering to create, design, new or better products, devices, systems, technologies and manufacturing processes.

The other half depend heavily, particularly to increase productivity, on the goods services and technologies provided by the companies in these classifications.

It is estimated that about 50% UK's GDP is dependent on engineering, not 5 – 10% as is frequently stated.

Aerospace and Defence
Automobiles
Chemicals
Construction and Building Materials
Diversified Industrials
Electricity
Electronic and Electrical Equipment
Food producers and Processors
Forestry and Paper
Gas Distribution
Household Goods and Textiles
Information Technology Hardware
Mining
Oil and Gas
Packaging
Pharmaceuticals
Software and Computer Services
Steel and other Materials
Telecommunication Services
Tobacco
Transport
Water

Attachment E

Letter to Lord Sainsbury from Sir David Davies dated 7 February 2000

Innovation and the contribution of Engineering

Akio Morita, founder of Sony, in the first DTI-sponsored UK Innovation Lecture, very effectively made the point that engineering is the process whereby science is converted to technology and engineering is the principal activity, along with marketing, that turns technology into successful innovation. Engineering makes innovation happen. It is easy to forget this when the word ‘Science’ is used as a shorthand term to describe ‘basic science, engineering and technology’. All of these contribute to innovation.

The following examples from the worlds of health, construction, foods and aerospace demonstrate the part that engineering plays in relation to science and technology.

Healthcare

The progress that has been made in ultrasonic imaging, so that ultrasound is now second only to X-rays in utilisation for medical investigations, has resulted from a continuous cycle in which engineering responds to the opportunities revealed by science and vice versa. For example, the improvements in ultrasonic transducer technology that have resulted from engineering development led to the recent serendipitous discovery of second harmonic imaging, now featured in many modern clinical scanners. This has improved the clarity and usefulness of the clinical images significantly. It has also opened up a new area of scientific research into the physics of ultrasonic interactions.

For many years after the discovery of lasers, they remained devices in search of applications in medicine. As the result of engineering advances in laser performance and light delivery systems, lasers are now widely used for bloodless surgery and therapies including those dependent on photosensitised drugs. Moreover, ongoing research into novel diagnostic applications which have the potential safely to provide complementary and additional information is dependent as much on engineering as it is on science.

The phenomenon of nuclear magnetic resonance was discovered more than fifty years ago. The development of scanners for magnetic resonance imaging has been one of the greatest achievements of recent times. Magnetic technologies of various kinds, cryogenic technology, precision mechanical engineering, high-power analogue and fast digital electronics, computing and visual display systems have been successfully developed and integrated into clinical instruments which are representative of the most advanced engineering in the world today.

More than four million people in the world today enjoy a reasonable quality of life only because their hearts are sustained by implanted artificial pacemakers. Very many would certainly otherwise be dead. Understanding the electrophysiology of cardiac function in health and disease is the essential starting point, but would be of little therapeutic value had not engineers developed the tiny, reliable and intelligent devices that electrically stimulate the otherwise failing heart, respond to variations in demand and even, in some circumstances, shock the heart to return it to its normal rhythm.

It is a misconception to think that medical engineering is merely a provider of tools for scientific research and medical practice. In many respects, medical engineering is a research subject in its own right. For example, the development of biomaterials (defined by The Royal Academy of Engineering as "any material, natural or man-made, or device that comprises whole or part of a living structure which performs, augments or replaces a natural function within a living organism) depends on multidisciplinary research involving collaboration between biologists, clinicians, material scientists and engineers. The tremendous success that has been achieved in the UK in bringing novel biomaterials to the market place has been substantially due to the overall co-ordinating role that has naturally been assumed by engineers.

Construction

The introduction of a new technology in engineering is a process which, for all the right reasons, is long and hard. In civil engineering particularly, the life of structures using the new techniques will be measured in decades up to specified design lives of 120 years or more. In the late 1970's Tensar high strength polymer geogrids (invented by the late Dr Brian Mercer FREng FRS) were developed to reinforce soils and permit the economic construction of steep, grass faced embankments, vertical retaining walls and thin road pavements over soft ground. Polymer science helped to develop the product but the polymer scientists knew little of the likely engineering applications or the required engineering properties. On the other hand the civil engineers who would design the structures knew little of the polymer science which was necessary to determine in advance the long-term performance of the new material. To be able to exploit the invention in a traditionally cautious industry it was important for the manufacturing company, Netlon Ltd, to forge strong links between the scientists and the engineers in order to define the product performance characteristics in both the short and the long term. The Science and Engineering Research Council Co-operative Grants Scheme was the mechanism by which the company was able to co-ordinate the activities of researchers at five UK universities as well as polymer suppliers, consulting civil engineers and a local authority. The success of the project can be measured by the fact that Tensar products are now manufactured in the UK and under licence in the USA and Japan and are widely used in many civil engineering projects all over the world.

Aerospace

The development of modern large aircraft engines provides a clear example of how a consistent investment in science and engineering research and its exploitation through technology underpins the aerospace industry. Since the introduction of the first large airliners in 1960, fuel consumption and thereby carbon dioxide emissions have been reduced by almost 60%. Emissions of nitrogenous oxides is currently well below international regulations and noise production has been reduced by 75%. For a company such as Rolls-Royce this track record has been established by continuous investment in engineering research turning around £500 million of funds into knowledge over the last decade. The transformation of this knowledge into successful products through technology has required an investment in new product development of £2.5 billion over the same period. This investment has resulted in the £3.7 billion annual turnover of Rolls-Royce's Aerospace group today.

Engineering provides a vital link in the process of turning the outcome of basic science – knowledge – into technology and a successful product. A fundamental understanding of the laws of aero- and thermodynamics alone is not sufficient to design a competitive aircraft engine. It requires a focused investment in materials sciences delivering innovations such as single crystal nickel alloys, manufacturing technology enabling new fan blade designs and computer sciences enabling advanced computational fluid dynamics to improve efficiency and reduce fuel burn. Similarly, the chemical combustion processes in the combustion chamber need to be understood in detail to be able to drive them toward even lower emissions. The science of aero-acoustics finally, has made a vital contribution toward understanding of engine noise but it requires the application of this knowledge through innovative ideas such as sound absorbing materials to reduce noise production. The exploitation of new ideas and processes – innovation – has enabled Rolls-Royce to build world-class products that compete successfully in high technology markets whilst reducing the environmental impact of their operation.

Foods and domestic products

Innovation takes many forms but commercial success in competitive markets is the common factor. Competition is as fierce in the foods and domestic products sector as in any other and science, engineering and technology all play their part. Two examples from Unilever plc's 1998 Review demonstrate this very well. To quote:

"Our new any-time ice cream snack *Winner Taco* has been successfully rolled out throughout Western Europe. Patents protect the product's ground-breaking manufacturing processes, which include using infra-red heaters to soften and fold the wafers.

Technology and innovation is boosting the quality and cost effectiveness of Unilever's manufacturing and supply chain. For example, improvements to our washing powder manufacturing processes in Brazil have allowed a 50% cut in capital and raw material costs. This technology has allowed us to launch a new competitively priced brand called *Ala*".

What is evident to those who study such examples is that such successes need good science, good technology and good engineering to make it all happen.