EDUCATING ENGINEERS FOR THE 21ST CENTURY

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1. Introduction

Amongst the greatest challenges we face in the world today are those of delivering growing, secure and affordable supplies of clean water and of energy, to meet the needs and expectations of an expanding population, whilst reducing our CO_2 emissions and the human contribution to climate change. The implementation of innovative engineering solutions is fundamental to addressing these challenges, whilst also offering exceptional opportunities for economic growth to the nations which are able to deliver them.

Yet at this time when our need for engineering talent is huge, and when our young people are increasingly interested in how they can help to save the planet, we are failing to persuade them that engineering careers are exciting, well-paid and worthwhile. The report concludes that we will face an increasing shortage of graduate engineers in the UK unless action is taken. The main focus of the working party's review has been the quality and relevance of engineering undergraduate education in the UK. In particular, its fitness for purpose in this age of the 'Knowledge Economy', now that developed countries must rely increasingly on intellectual capital for their competitiveness.

Encouragingly, industry and academia are in close agreement on the key issues and what needs to be done. The university respondents would welcome closer collaboration with companies to ensure that our graduates can apply their knowledge effectively in real engineering situations and the opportunity to develop and implement new courses and approaches. It is essential that we provide the right conditions in university engineering departments for such university/industry partnerships, as well as new approaches to learning and teaching, to flourish.

I would like to thank the members of the working party:

Professor Graham J Davies FREng: Head of School of Engineering, University of Birmingham **Professor Peter J Goodhew FREng:** Engineering Department, Liverpool University **Professor Geoff E Kirk RDI, FREng:** formerly Chief Design Engineer [Civil Aerospace] - Rolls-Royce plc **Professor David A Nethercot OBE FREng:** Head of Department, Department of Civil & Environmental Engineering, Imperial College London **Mr Hugh Norie OBE FREng:** Project Director DFT Channel Tunnel Rail Link **Professor John F Roulston OBE FREng FRSE:** CEO Scimus Solutions **Dr Julia C Shelton:** Reader in Medical Engineering, Queen Mary, University of London **Professor Michael J Withers FREng:** RAEng, Visiting Professor in Principles of Engineering Design Loughborough University for their thoughtful, constructive and challenging inputs to this work.

The working party would not have been able to undertake the study without the excellent support of The Royal Academy of Engineering team:

Dr Robert W Ditchfield: Director, Education Affairs **EurIng Ian J Bowbrick:** Manager, Postgraduate and Professional Development **David M Foxley:** Manager, Engineering Design Education

Many other people have made valuable contributions. These include the staff of companies listed in Appendix 3 who answered our questions and returned the questionnaire, senior academics from the universities listed in Appendix 5 who responded to the consultation, participants in the meeting at the Royal Society of Arts, held to launch the results of the Industry Study and the Academy's Visiting Professors of Design, who, at their annual conference in September 2006 provided excellent, action-oriented inputs. The working party members would like to thank all of those who have been involved.

Professor Julia E King CBE FREng
Vice Chancellor Aston University
Chair of the Educating Engineers for the 21st Century Working Party
June 2007

2. Overview

No factor is more critical in underpinning the continuing health and vitality of any national economy than a strong supply of graduate engineers equipped with the understanding, attitudes and abilities necessary to apply their skills in business and other environments.

Today, business environments increasingly require engineers who can design and deliver to customers not merely isolated products but complete solutions involving complex integrated systems. Increasingly they also demand the ability to work in globally dispersed teams across different time zones and cultures.

The traditional disciplinary boundaries inherited from the 19th century are now being transgressed by new industries and disciplines, such as medical engineering and nanotechnology, which also involve the application of more recent engineering developments, most obviously the information and communication technologies. Meanwhile new products and services that would be impossible without the knowledge and skills of engineers - for instance the internet and mobile telephones - have become pervasive in our everyday life, especially for young people.

Engineering businesses now seek engineers with abilities and attributes in two broad areas - technical understanding and enabling skills. The first of these comprises: a sound knowledge of disciplinary fundamentals; a strong grasp of mathematics; creativity and innovation; together with the ability to apply theory in practice. The second is the set of abilities that enable engineers to work effectively in a business environment: communication skills; team-working skills; and business awareness of the implications of engineering decisions and investments.

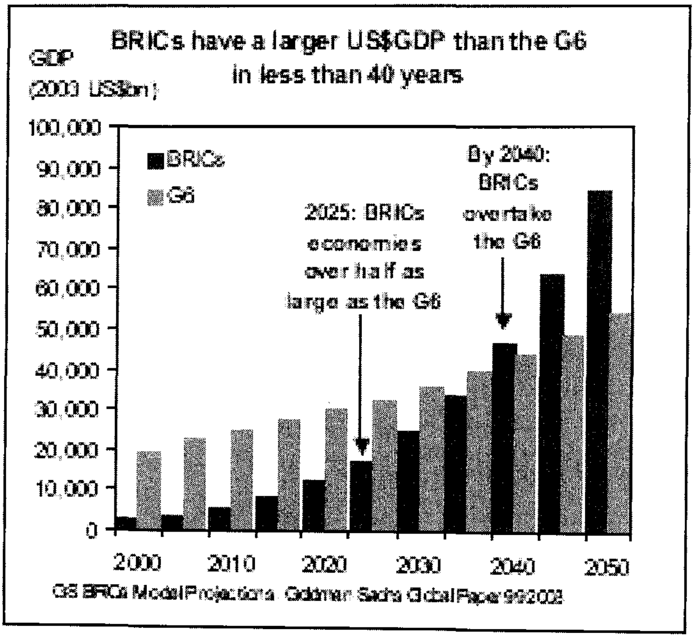
It is this combination of understanding and skills that underpins the role that engineers now play in the business world, a role with three distinct, if inter-related, elements: that of the technical specialist imbued with expert knowledge; that of the integrator able to operate across boundaries in complex environments; and that of the change agent providing the creativity, innovation and leadership necessary to meet new challenges.

Engineering today is characterised by both a rapidly increasing diversity of the demands made on engineers in their professional lives and the ubiquity of the products and services they provide. Yet there is a growing concern that in the UK the education system responsible for producing new generations of engineers is failing to keep pace with the inherent dynamism of this situation and indeed with the increasing need for engineers.

In the secondary schools, where students make decisions about the university courses they will pursue, there is an acknowledged shortage of teachers in maths and physics, the essential precursors of undergraduate engineering studies. In the universities the structure and content of engineering courses has changed relatively little over the past 20 years, indeed much of the teaching would still be familiar to the parents of today's new students.

Right now in the UK even the basic output of engineers is effectively stagnating. Between 1994-2004 the number of students embarking on engineering degrees in UK universities remained static at 24,500 each year even though total university admissions rose by 40% over the same period. Further, after completing their studies less than half of UK engineering graduates subsequently choose to enter the profession [1].

International developments make the implications of this situation even more disquieting. Mature economies, such as that of the UK, must now compete with those of rapidly developing countries such as the BRIC nations - Brazil, Russia, India and China. On current projections the combined GDPs of the BRIC nations are set to overhaul those of the G6 countries (US, UK, Germany, Japan, France and Italy) by the year 2040 [2]. Furthermore the BRIC nations are producing record numbers of graduate engineers. In China and India alone, the most conservative estimates suggest that around half a million engineers now graduate each year [3].



Consequently countries like the UK face the double challenge: producing increased numbers of a new type of engineer. The long term implications of a failure to confront this situation are self-evident. Ultimately the UK could slide into insignificance as an internationally competitive industrial nation.

Action is needed to counter and reverse these trends. But such action must be based on reliable, in-depth information on several key issues. These include: the current state of undergraduate engineering education in terms of its quality, content and funding needs; future industry requirements; accreditation procedures; and the extent to which the school system is ensuring a healthy 'pipeline' of engineering undergraduates.

For these reasons The Royal Academy of Engineering set up a working group specifically to address the issue of Educating Engineers for the 21st Century, chaired by Professor Julia King. The group commissioned extensive research within both UK industry and the universities; altogether over 400 companies and nearly 80 university engineering departments have been involved. The membership of the Educating Engineering for the 21st Century Working Group is listed in the Chair's Foreword on page 3; the terms of reference appear in Appendix 1.

This report is a summary of the findings of that research and the resulting actions proposed by The Royal Academy of Engineering. The major findings of the research are that:

- the best of UK graduate engineers are still world class and industry is generally satisfied with their overall quality, but there are simply not enough of them;
- engineering courses at UK universities are now seriously under-funded;
- the funding and ranking-driven focus on research in many universities is constraining the development of innovative learning and teaching in engineering;
- universities and industry need to find more effective ways of ensuring that course content reflects the real requirements of industry and enabling students to gain practical experience of industry as part of their education;
- the accreditation process for university engineering courses should be proactive in driving the development and updating of course content, rather than being a passive auditing exercise;
- reform of the engineering qualifications system at a European level must be focussed on the importance of output competences as the primary means of assessing educational achievement;
- much more must be done to ensure that school students perceive engineering as an exciting and rewarding profession that is worth pursuing;
- foreign graduates of UK engineering degree courses should be allowed to work in the country for an extended period (more than one year) after completing their studies;
- unless action is taken a shortage of high-calibre engineers entering industry will become increasingly apparent over the next ten years with serious repercussions for the productivity and creativity of UK businesses.

Addressing this situation requires urgent initiatives on the part not just of industry and the universities, but also of Government, the engineering institutions, the ETB and The Royal Academy of Engineering itself. The objective must be a step change in the number of students entering engineering degree courses without any compromise to the quality of qualification they eventually receive.

3. Research Process

This report has been produced on the basis of extensive consultation with industry, the universities and recent engineering graduates. It represents the most comprehensive recent survey of attitudes, expectations and experiences amongst the key customers, providers and recipients of engineering education in the UK.

4. The Industry Study

The first step in the consultation process was an industry study carried out on behalf of the Academy by Henley Management College during 2005. The study began with 21 in-depth interviews with senior personnel in major companies in the manufacturing, energy and process sectors, civil engineering, IT and the utilities. It was followed by a further 13 interviews with SMEs, seven of which were high-tech spin-outs from UK university engineering departments. In addition three focus groups were conducted with recent engineering graduates. The companies involved are listed in Appendix 3.

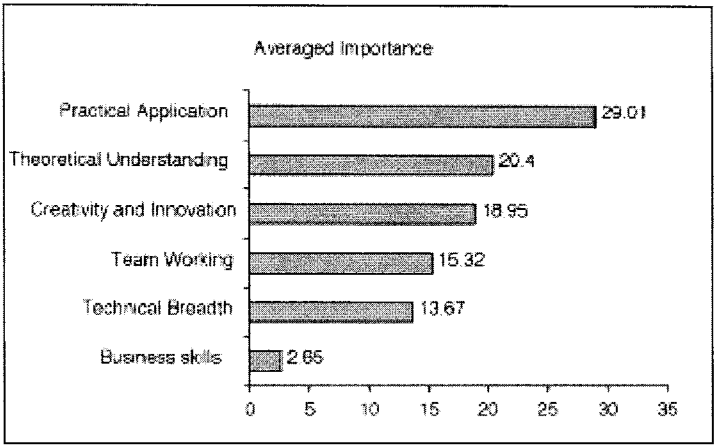
The information gained was used to formulate a detailed questionnaire that was distributed to over 8,000 further engineering companies. The questionnaire sought to obtain information in four main areas:

- changes in the industry;
- current and future skills requirements;
- the comparative quality of UK and international engineering graduates;
- consequential requirements for changes in engineering degree courses.

Altogether 444 replies to the questionnaire were received, a response rate of 5.4%; more than double the usual rate for such exercises. Moreover 53% of the companies responding were SMEs. This response rate is strong evidence of the importance attached to the issue within industry. The Academy working party's Commentary and the full report on the industry responses are available for download from the Academy's website at www.raeng.org.uk/henleyreport

The research indicated that industry expects that the supply of high calibre engineering graduates will steadily diminish over the next ten years with serious and direct repercussions for productivity, creativity and hence profitability. Current shortages of graduate recruits in Civil, Electrical, Electronic Engineering and Systems Engineering were all highlighted. Companies identified Information and Communications Technology and Materials as key areas for increased graduate recruitment to support future growth.

Companies are concerned about the type of graduate engineer they want to recruit, as well as their quantity. Although industry is generally satisfied with the current quality of graduate engineers it regards the ability to apply theoretical knowledge to real industrial problems as the single most desirable attribute in new recruits. But this ability has become rarer in recent years - a factor which is seen as impacting on business growth. In descending order of importance other relevant attributes for graduate engineering recruits identified by industry include theoretical understanding, creativity and innovation, team working, technical breadth and business skills.



The prominence of creativity and innovation endorses the conclusion of the Cox Review on the importance of creative skills in improving the UK's competitiveness in the face of the challenge from emerging economies [5].

Although business skills come last in the ranking of industry requirements, industry is nevertheless quite specific about the nature of such skills it wants graduate engineers to possess. These are general commercial awareness defined as an understanding of how businesses work and the importance of the customer - combined with a basic understanding of project management.

Significantly the research found little difference between the requirements for graduate engineering skills of major companies and SMEs. The only difference of note is that SMEs have a distinct preference for graduates with some experience of the commercial world, whereas major companies with their own graduate training schemes tend to recruit directly from universities. Less than half the SMEs that responded to the survey operate graduate training schemes of their own, whereas almost 90% of the large companies reported having such schemes in place.

Measures to support the introduction of structured graduate training schemes within the SME sector could, therefore, prove of great value. This is an area in which public sector bodies such as the RDAs or professional bodies such as the engineering institutions could become involved. It is also an area in which larger companies could usefully provide support to the SME community, possibly as part of their supply chain development policies.

Real industrial experience, however, remains a primary factor in the recruitment policies of the great majority of companies and is highly influential in determining the selection of job applicants for interview. The need to ensure that students gain practical experience of real industrial environments during their studies is therefore extremely important. This perception is shared by students themselves, since the graduate focus groups expressed concern about limited and unrealistic project work they had experienced during their degree courses.

The resulting report on industry's views, together with the Academy's Commentary, was formally launched at a Symposium held in London on 30 March 2006 by Lord Sainsbury of Turville, Parliamentary Under Secretary for Science and Innovation. The Symposium reviewed the international context, with particular reference to The Engineer of 2020 study of the US National Academy of Engineering, as well as subjecting UK industrial requirements to further analysis [6].

5. The University Consultation

A second questionnaire was then distributed to all university engineering departments with the aim of establishing the extent of university agreement with industry and the actions that were already underway within the universities to develop the engineering curriculum. Altogether 81 responses were received, which showed no significant variation in views between Russell Group, other 'pre-92' and 'post-92' universities. Appendix 5 lists the universities involved.

Amongst the most important findings of this academic survey were the close correlation between the views of industry and the universities on the major issues concerning undergraduate engineering education and the confirmation it provided of the enthusiasm of the universities for closer collaborative links with industry. University engineering departments, for instance, overwhelmingly concurred with the view that their courses need to provide more experience in the application of theoretical understanding to real applications of the type graduates would encounter once they enter industry. The primary means of satisfying this objective is through problem-based learning approaches combined with design/make activities and other types of individual and group project work in which students can see the opportunities and the necessity for innovation. Where they can be incorporated, course placements and projects in industry are also a major benefit. But in turn such work makes a number of demands of its own including familiarity of academic staff with real industry problems through close relationships between academic departments and companies at the teaching level, provision of challenging case study material from industry and the availability of adequate laboratory facilities within the universities themselves.

These requirements emphasise the issue of funding, which is currently a cause of great concern within the university engineering community. Engineering courses used to be funded by HEFCE at a rate of twice the basic unit of resource, but over the period 2003-04 this was ratio was reduced to just 1.7. However there is universally held view within universities that this allocation needs to be at least 2.5 and possibly as much as three times the basic unit if engineering courses are to meet future requirements for enhanced engagement with industry including more extensive design and project work.

Further, the effectiveness of all aspects of the undergraduate engineering experience, not just project work, depends on the quality of the teaching. Whilst the quality of teaching is generally enhanced by staff involvement in research, so called 'research-led teaching', there is also a widespread view that the current funding regime, so strongly driven by the Research Assessment Exercise (RAE), has inhibited the development of innovative teaching practice. Staff time must be allocated between research, teaching and administrative duties but there is strong perception of inadequate incentives and rewards for teaching compared with research. Despite the fact that most universities have a formal commitment to recognising teaching expertise in their appointment and promotion processes, many of those involved feel that research activities and even administrative expertise are given undue weight.

UK universities are also anxious about the moves currently taking place at a European level to achieve 'Bologna compliance', effectively the harmonisation of the required standards for engineering degree courses, but primarily through an approach based course length. Specifically they want to ensure that the current UK four-year MEng degree course structure is recognised as fulfilling all the relevant requirements through its delivery of a compact syllabus in an integrated manner and that there is no need to adopt the five-year format used elsewhere in Europe. A major fear is that failure to defend the integrity of the existing UK degree structure might devalue UK degrees in the eyes of potential overseas students, whereas increasing the length of degrees to 5 years could discourage UK students from studying engineering.

Nevertheless the overall picture also contained some positive elements. Nearly three fifths of the academic respondents, for instance, were implementing elements of the CDIO (Conceive, Design, Implement, Operate) approach to learning and teaching which puts an emphasis on articulating and solving problems as a lead in to developing the important but more abstract analytical skills, a highly appropriate approach for engineers [7]. Around three quarters also expressed support for the introduction of new types of engineering course, such as biotechnology or nanotechnology. In addition just over half reported they had had contact with at least one or other of the HEFCE-funded Engineering Subject Centre (engSC) or the UK Centre for Materials Education.

Overwhelming enthusiasm was expressed for greater industrial involvement in the education process, something already implemented through initiatives such as the Academy's Visiting Professors scheme. One useful way in which greater involvement could be effected would be through increased participation by practising engineers in the accreditation process for degree courses, a measure that would help ensure that course content is developed in sympathy with the real requirements of industry. This would be particularly valuable in the case of newer courses, such as Systems Engineering or Bioengineering, of a multi-disciplinary nature that do not obviously fall under the remit of a single engineering institution.

The information gathered from these studies subsequently informed much of the discussion at the conference of the Academy's Visiting Professors schemes in Engineering Design, Sustainable Development and Integrated Systems Design held at Churchill College, Cambridge, on 12-13 September 2006. The conference provided confirmation that the schemes are widely acknowledged as popular and successful in helping universities develop in students the 'applied competences' they will increasingly require as practising engineers.

The conference also explored the role that the schemes could play in the future education of engineering students. There was a broad consensus that the Academy's schemes could be further developed to the benefit of engineering education with actions including the accelerated introduction of the planned Visiting Professors in Innovation and the inception of a Visiting Lecturers initiative to support the involvement of less senior engineers from industry in university learning and teaching activities.

6. Key Messages

The research on which this report is based identified a marked degree of consensus amongst both industrial and academic respondents about the current situation in the universities, industry requirements and necessary actions. The Academy Working Group has used the industry and academic inputs to formulate the following nine Key Messages.

6.1. *Over the next ten years the UK is facing an increasing shortage of high calibre engineering graduates entering industry, just at the time we need a growing number if businesses are to remain competitive and the UK is to attract high technology inward investment.*

•Business and the professional institutions must do more to ensure that UK students recognise the attractiveness and rewards of an Engineering career.

•Overseas students choosing to study engineering in the UK bring significant benefits. They are often students of high calibre, with a stronger mathematical training than their UK peers, who add important international elements to the educational experience. In many universities overseas students are essential in maintaining the viability of engineering courses. It is critical that we continue to attract such students to the UK, by both ensuring that our engineering courses maintain a high reputation and by allowing them to work in the UK on graduating.

•Allowing overseas engineering students to remain for at least five years after graduation would: (i) encourage students from rapidly developing countries to choose to study engineering in the UK universities as they will be able to work in the UK for long enough after graduation to repay their loans, and (ii) provide UK-based companies with a larger pool of world-class engineering talent to draw on. The current situation where overseas graduates can only remain in the UK for one year makes them less appealing recruits because this is not long enough to recover company investment in their training, and to make a significant contribution to company's (and the UK's) success.

•In the longer term we will require measures to stimulate greater numbers of school students to study maths and physics, to encourage them to become engineering undergraduates and finally to opt to apply their qualifications in industry.

6.2. ***University engineering courses must provide students with the range of knowledge and innovative problem-solving skills to work effectively in industry as well as motivating students to become engineers on graduation. To do this courses must be adequately resourced - this implies significantly more funding per head than at present.***

•Engineering is an intrinsically expensive subject to teach well because of the demands it makes for small group work in design and build projects, specialist laboratory equipment and technician support. These elements of the learning experience are cited as critical by both recent graduates and employers in developing innovative, entrepreneurial graduates who can tackle open-ended problems

•In the context of the current HEFCE funding formula this requires an increased level of support of the order of 2.5 to three times the basic unit of resource (compared to the current allocation of 1.7)

6.3. ***The best UK engineering graduates are world class and compare favourably with those of other countries in Europe and elsewhere. It is important that the MEng qualification is not undermined by the development of the proposed European Qualifications Framework under the terms of the Bologna agreement.***

•Industry welcomes the current diversity of paths to engineering degrees across Europe; this enables companies to recruit engineers with a wide range of skill sets.

•Course assessment based on output competences, rather than student work-load, must be promoted as the basis for a European Qualifications Framework (to replace the European Credit Transfer System), as part of the Bologna process. It is essential that the Government take a proactive role in promoting this output-competence-based approach in all Bologna negotiations and agreements.

•In the meantime engineering departments are encouraged to ensure that they comply with Universities UK guidelines (Europe Note E/05/12), in order to satisfy the requirements for Bologna convergence.

•Within the UK it is desirable for there to be a single focal point for engineering to coordinate implementation of the Bologna qualification framework; the Engineering Accreditation Board (EAB) is well placed to take on this role.

6.4. ***Engineering courses must develop in line with the real and constantly evolving requirements of industry. Regulation and maintenance of standards should encourage and enable change rather than inhibit.***

•To ensure that UK engineering education is world-class, academic staff need the time and resources to implement new approaches to engineering learning and teaching, an example of which is the Conceive, Design, Implement and Operate (CDIO) framework.

•There is a need to embed multidisciplinary approaches based on systems thinking, with strong industry links, within all engineering courses.

•New courses which appeal to a wider range of students, and particularly women undergraduates, such as Bioengineering and Medical Engineering, should be encouraged. But engineering must avoid the 'forensic science' trap of training graduates in fashionable subjects for jobs which do not exist. We must ensure that all new courses retain a strong core engineering content, both in terms of depth and quality, such that graduates can be employed in a wide range of professional engineering roles.

6.5. ***The prestige of and resource for teaching in research-active engineering departments have been compromised by a disproportionate emphasis on the research output as a consequence of the Research Assessment Exercise.***

•Teaching must be seen as central to academic career prospects and be suitably rewarded through promotion and remuneration. There must be appropriate incentives for academic staff to develop new learning and teaching approaches and new types of course content.

•Three actions will support this: (i) a proper level of funding for undergraduate engineering teaching; (ii) the development and adoption of quantitative, challenging promotion criteria for teaching to ensure that teaching achievements can be ranked equally alongside research in promotion criteria at all academic levels, and (iii) national and international engineering bodies should develop high profile awards to recognise engineering teaching.

6.6. ***Much more effective interaction between industry and university engineering departments is required. Support and engagement needs to operate at two levels: the provision by industry of strategic advice to help shape course development and operational engagement whereby students can experience real-life industrial engineering challenges.***

•Strategic advice on course development can be made through Industrial Advisory (or Steering) Committees as well as through the accreditation process

•Operational engagement should give students exposure to realistic, open-ended problems, teaching them relevant skills and motivating them towards careers in industry. Such engagement can take the form of Visiting Professors from industry (in which the Academy schemes play an important role), provision of project topics and facilities, visits, work placements and recruitment. Developing these industry/university relationships is important, but also time-consuming for both the company and the academic staff. Long term industry/academic

relationships at the teaching and recruitment level, such as are now working well for research, need to be developed.
•Industry respondents ranked industrial experience during training as the most important factor in terms of the employability and contribution of graduate recruits.
•This could be particularly significant for the development of SMEs. SMEs find it harder to take on work placement students because of the real or perceived diversionary impact. The diversionary costs for SMEs need to be supported, for example by 100% government/RDA funding or suitable tax incentives, along the lines of those awarded for R&D activity

6.7. *Universities must continue to teach 'core engineering' and not dilute course content with peripheral subject matter.*

• Industry's top priorities for engineering graduate skills are practical application, theoretical understanding, creativity and innovation.
•Whilst broader technological understanding is also important it should not be at the expense of understanding the fundamentals. It is important that courses are not overloaded with technical content: the emphasis should be on the ability to understand and apply theory to real problems.
•There is a limited requirement for training in key business skills, envisaged primarily as commercial awareness - an understanding of how businesses work and the importance of the customer - combined with the basic principles of project management.

6.8. *The accreditation process for engineering degree courses should actively inform the development of course content to ensure that courses produce graduates that industry will want to employ.*

•The accreditation process should have a stronger emphasis on recommending ways in which courses should be developed rather than just being a formal audit of current course content. Accreditation boards may need to ensure that courses are being developed to be Bologna - compliant.
•Accreditation panels should include current industry practitioners who can provide advice on how course content should be shaped to produce graduates with the knowledge, skills and aptitudes that industry genuinely requires. The Accreditation process offers one route for industry to comment on what will be needed for the future and thereby stimulate new thinking and course improvements.

6.9. To fill the "pipeline", more must be done to ensure that school students, parents and teachers perceive engineering as an exciting and worthwhile subject that offers stimulating and well-paid careers.

•Industry itself, and indeed government, must get involved in this process, especially in the critical task of ensuring that teachers and parents - by far the most crucial opinion formers for school students become convinced of the benefits of engineering as a career choice. Key messages are the value of engineering to society (energy, climate change, care of the elderly etc), the excitement of the technological challenges, and the good career prospects and salaries accessible through the study of engineering.
•Current initiatives to encourage school students to study mathematics and the physical sciences and to increase the number of science teachers are strongly welcomed.
•Similar encouragement should also be given for universities and companies to collaborate with other interested parties along the lines laid out in the Teaching Engineering in Schools Strategy (TESS) as envisaged in the National Engineering Programme (NEP).

7. Recommendations

Reshaping undergraduate engineering education in the UK to meet the demands of the 21st century will require input from the Government, the engineering profession, industry and academia. The major recommended actions are as follows:

7.1. *To Government*

•To increase university funding to cover the true cost of providing world-class teaching in engineering from the present factor of 1.7 to at least 2.5, and optimally three, times the basic unit of resource.
•To place teaching quality alongside research excellence in the assessment of the funding requirements for universities
•To enable overseas engineering students to work in the UK for a period of 5 years after graduation, enabling them to contribute to a high technology-based economy in the UK, and to pay off their loans
•To ensure that the Bologna process is managed so that UK degrees are preserved in their current form through the replacement of the European Credit Transfer System (ECTS) by an output competences approach in the new European Qualifications Framework.
•To increase the funding for engineering education initiatives which strengthen industry links such as the Visiting Professor schemes, and to enable the introduction of new schemes.

•To provide further funding to the Engineering Subject Centre (engSC) to enable it to expand and support the development and dissemination of best practice in engineering education.
•To support sandwich-type placements in both small and large companies either through RDA funding or through tax incentives, akin to those recommended in the Cox Review, to provide greater incentives for creativity and design.
•To continue to implement the Science, Technology, Engineering and Mathematics (STEM) Programme Report [8].
•To continue the programme of support for the training of more maths and physics teachers.
•To ensure that, in Government papers and announcements on major policy and societal issues, the opportunity is taken to highlight the important role of engineering in providing solutions - for example in energy, transport and care of the elderly .

7.2. *To the Engineering Institutions*

•To help raise the profile and status of university teaching in engineering, for example through high profile awards for excellence and innovation in engineering teaching and learning.
•To make the accreditation process a strategic tool for ensuring continued relevance of courses to the real needs of the economy. The accreditation process should encourage course development and innovation, taking greater account of the professional competencies and fitness for purpose of the graduates whilst being less prescriptive on specialist technical content.
•To establish processes which support the creation, development and accreditation of multidisciplinary degrees.
•To engage actively with the Government's STEM programme.
•To be proactive in strengthening the university/industry interface through cooperation, liaison and promotion of activities, such as Formula Student.

7.3. *To Industry*

•To establish active, long-term relationships with university engineering departments in the area of education (as many companies have now done in research), including membership of Advisory Boards, providing Visiting Professors and Industrial Tutors, offering project topics and facilities and student placements. Companies should also recognise the secondary benefit from such engagement, for example in the development of younger staff.
•To engage actively with the Government's STEM programme.
•To work with the Institutions in degree accreditation, in particular releasing active members of staff to serve on the Accreditation Boards and Panels.

7.4. *To the Academy*

•To enlarge and expand the Visiting Professors Schemes in Engineering Design - to disseminate current industrial best practice, to address the Innovation and Creativity agenda, and to embed integrated systems design principles into all degree courses.
•To work with companies and universities to develop new links and opportunities for exchange of personnel, eg by the introduction of a Visiting Lecturer scheme and secondments for academics to spend time with companies developing new teaching materials.
•To continue to take the lead, through TESS, Shape the Future and the Best programme, in coordinating activity to 'fill the pipeline'.
•To make greater use of the younger people in the Best Programme and other Academy schemes to provide feedback to university departments.

7.5. *To University Engineering Departments*

•To recognise the importance of excellent and innovative course design and delivery through promotion criteria and reward.
•To strengthen links with industry in education and teaching.
•To improve understanding in academia of the skills and competences of engineering graduates required by industry, to ensure that courses produce graduates with a high level of relevant technical competence backed up by the ability to apply it.
•To be proactive in developing world-class degree courses for the 21st Century, including courses which are attractive to underrepresented groups such as women.
•To continue to engage actively in STEM initiatives in schools by a proper allocation of the unit funding for widening participation.

7.6. *To the Engineering Technology Board (etb)*

•To intensify its role in informing students and their parents of the excitement and importance of engineering and the excellent career prospects of engineering graduates.

7.7. *To the Engineering Subject Centres*

•To expand their role in developing and disseminating best practice in engineering education and in promoting and rewarding innovative teaching.
• To develop specialist promotion criteria for engineering learning and teaching which enable such contributions to be compared with quantitative research criteria, such as research income and publications, in academic promotion processes.

8. References

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6. The Engineer of 2020, National Academy of Engineering, Washington DC, 2004.
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9. Appendix 1

Educating Engineers for the 21st Century
Terms of Reference

- To draft an Academy policy statement on the changes required in the engineering education curriculum for the formation of the professional engineers required in the 21st Century.
- To take account of the following aspects in the study:

  The need to ensure that the UK can strengthen its position as a centre for world class high value added engineering.

  The Business and Industry Requirements with particular reference to the requirements and preferences of International Business following the Bologna Declaration.

  The nature and length of engineering degree courses with particular reference to the impact of the Bologna Declaration and the changes occurring in pre-university education.

  The process of Regulation and Accreditation. The most effective ways to recruit high caliber students.

  Overseas developments and best practice.
- To complete and present the study to The Standing Committee for Education and Training.

10. Appendix 2

Educating Engineers for the 21st Century: The Industry View

Conclusions from the Industry Study

The Academy's Working Party and Fellows on the Standing Committee for Education and Training have identified the following major conclusions from the study of industry views.

10.1. ***Over the next ten years there will be a worsening shortage of high calibre UK engineering graduates going into industry. This shortage will impact the productivity and creativity of UK-based businesses unless it can be addressed.***

In several areas, companies in the survey report difficulties today in recruiting graduate engineers. Many comment that it is difficult to get 'enough of the best'. But they expect graduate engineers to make up an increasing proportion of the workforce over the next ten years. The latter point is encouraging in the light of the aim, stated in the White Paper on Innovation [9], to raise UK R&D spending from 1.9% to 2.5% of GDP by 2014. Nevertheless companies are concerned about the 'pipeline' of suitably motivated and qualified young people in schools equipped to progress to engineering degrees.

10.2. ***Shortages of suitable engineering graduates and skill gaps are impacting the performance of UK businesses.***

Over one-third of companies responding indicate that shortages and skill deficiencies are impeding new product development and business growth, as well as increasing recruitment costs. Specific gaps exist in problem solving and application of theory to real problems ,breadth and ability in maths.

10.3. ***University courses need to provide more experience in applying theoretical understanding to real problems.***

Whilst industry is generally satisfied with the engineers it recruits, there are concerns about the ability of graduates to apply their knowledge to real industrial problems. This has become more acute in recent years and is identified as one of the skill shortages impacting business growth.

The graduate focus groups also expressed concern about limited and 'unrealistic' project work in their degree courses. Project work was nevertheless identified as the most important element of their education in terms of their subsequent experience in industry.

Over the past ten years the unit of resource for teaching an engineering undergraduate has fallen by a factor of two to three. This has led to a reduction in expensive practical and project work and an increased reliance on computer-based models in place of real experiments. At the same time academic staff members have been focussed on increasing their research outputs to improve performance in the Research Assessment Exercise, leaving teaching as a 'poor relation' in terms of competition for staff time and commitment in our leading universities.

10.4. *The quality of the best UK graduates is as good as their peers in Europe, despite our shorter degree courses.*

Companies expressed concern over the additional costs/debts associated with the four year MEng, compared with a BEng. There was no evidence of a strong desire to move to five years in line with other parts of Europe.

It is important that we achieve 'Bologna compliance' within the four-year MEng structure for UK engineering degrees to ensure that both our students and courses remain highly marketable in other parts of Europe. UK universities will need government support to ensure that further negotiations allow for this outcome, while HEFCE will need to recognise the additional cost of new elements which may be required to achieve compliance.

10.5. *UK engineering degree courses must: recognise the changing requirements of industry; attract and maintain motivation of students; ensure UK degrees continue to be recognised in Europe.*

In terms of priorities for future graduate skills, respondents present a very consistent picture. Practical application, theoretical understanding and creativity and innovation are seen as the top priorities. Whilst broader technological understanding is also important, it should not come at the expense of understanding the fundamentals. Key business skills are envisaged primarily as commercial awareness or sensitivity - an understanding of how businesses work and the importance of the customer - combined with a basic understanding of project management.

The perspective of the graduates in the focus groups mirrored the business respondents and emphasised what motivates students to study engineering: a good all round degree course offering a wide range of career options, a strong sense of wanting to make a difference, contributing to society and being able to see the results of their creativity.

Closer collaboration between industry and universities in the area of undergraduate education is a key requirement going forward.

10.6. *Industrial experience is a major factor in recruitment of new graduates.*

A large majority of companies report using industrial experience, whether before or during university as an important discriminator in selecting job applicants for interview.

10.7. *Large companies and SMEs have very similar requirements for graduate education and skills.*

Few differences emerged between the needs of large and small to medium-sized companies in the survey, in which half of the respondents employed less than 500 personnel. But one that can be identified is that SMEs prefer graduates with some experience of the commercial world before recruitment, whereas large companies recruit directly from universities and have their own graduate training schemes.

10.8. *Structured graduate training schemes are needed to support SMEs*

Whilst almost 90% of companies with over 500 employees report having graduate training schemes in place, more than half of the SME respondents do not. This provides an opportunity for organisations such as the sector skills councils, professional institutions and RDAs to become involved and for large companies to work with SMEs in their supply chains to offer provision for graduate training and mentoring.

11. Appendix 3

Companies involved in the Industry Study
The following companies were interviewed for this study:

• ABB	• Grimley Smith Associates
• Arup	• IBM
• Atkins	• Lightweight Medical Limited
• BOC Edwards	• National Grid Transco
• BP plc	• Nortel Renishaw plc
• BT Group (2 interviews)	• Roll-Royce plc
• Cadogan Consultants	• Shell UK

• Cold Drawn Products • Cultech Limited • DSTL • Filtronic plc • Ford Motor Company Ltd • Foster Wheeler Energy	• Siemens UK • Smiths Group plc • Technical Support Associates • Thales UK plc • Thames Water

In addition seven interviews were conducted with key informants involved in spin-outs that had emerged from four UK universities: Brunel, Cambridge, Imperial College and Oxford. The names of the companies have not been included for reasons of commercial confidentiality.

A further 444 companies responded to the industry questionnaire.

12. Appendix 4

Educating Engineers for the 21st Century
Analysis of Responses to the University Questionnaire

12.1. *Over the next ten years there will be a worsening shortage of high calibre UK engineering graduates going into industry.*

The majority (87%) agreed with this. While some universities (27%) aspire to increase both quality and quantity within the current funding environment the majority (68%) are aiming to maintain the same numbers and entry standards. It is anticipated that the number of graduates entering industry will remain at current levels.

12.2. *There is a need for more inspiring engineering degree courses.*

The majority (80%) are in agreement that this is a key aspiration. It is generally considered that all universities should continually strive to improve their courses in terms of technical content, pedagogy, transferable skills, professional responsibility, management and project work as well as motivation and inspiration. Most believe that they are doing this within the constraints of the current accreditation process. However, there is a requirement for more degree programmes which cross nineteenth century institutional boundaries.

12.3. *There is a need for engineering degree courses with closer industrial engagement.*

There is widespread agreement (89%) that industry should supply more feedback on the quality and education of graduates and provide high quality project and case study material. Academics see themselves as responsible for designing courses to suit a wide range of aspirations in professional engineering whilst taking into account both intrinsic educational value and the views of potential employers. It must be stressed that many courses already have a large industrial content.

12.4. *University courses need to provide more experience in applying theoretical understanding to real applications and the open-ended problems faced by industry.*

There was again overwhelming agreement (91%) from respondents. While noting the need to build on theoretical knowledge ('the basics'), the requirement for 'real applications' and 'open ended' project and practical work are also well recognised. Given additional resources the majority of respondents would use them to refurbish, better equip and expand practical and laboratory facilities. This would also mean engaging increased numbers of technical support staff and developing more industry based case studies.

12.5. *The current stance on Bologna is that the quality of the best UK students is as good as their peers in Europe despite our shorter degrees.*

There was general agreement with this proposition, which was also endorsed by the industry survey. But it is difficult to make any direct comparison due to the lack of any formal benchmarking system.

12.6. *It is important that 'Bologna compliance' is achieved within the four-year MEng degree structure for UK Engineering.*

At departmental level there is surprisingly little activity in this area, though 52% claim to be doing something amongst whom most are 'awaiting advice from the university and/or the Engineering (degree) Accreditation Boards'. Very few (25%) are finding the Universities UK advice (Europe Note E/05/12) useful or easy to follow.

More significantly it is clear that few intend to take any positive action to conform to the Bologna process until they receive specific directions from either their university (through QAA, UUK or HEFCE) or from the engineering institutions licensed by EC^{UK} to accredit engineering degrees. Currently all Engineering degrees are accredited in accordance with UKSPEC and the EC^{UK}/QAA Engineering Degree Benchmark Statements in order to gain professional recognition. It is, therefore, a matter of paramount importance to issue detailed advice on how to present these requirements in such away as to be

'Bologna compliant'. Currently no UK body has been specifically tasked, or made accountable, for ensuring that this is done.

12.7. ***Are BEng degree courses being structured to comply with the first cycle requirements?***

Again most consider themselves already compliant but the formalities have yet to be completed.

12.8. ***Are degree standards being structured to comply with the EC^{UK}/QAA Engineering Benchmark Statements?***

The great majority of respondents (86%) have actively complied with this as it is now required by the Accreditation Boards. All relevant degree courses are accredited by the appropriate Engineering Accreditation Boards.

12.9. ***The Report identifies a hierarchy of Skills and Attributes (in decreasing order): Practical Application; Theoretical Understanding; Creativity and Innovation; Teamworking; Technical Breadth and Business.***

There is general agreement about the required skills and attributes, but not about the ranking. While a clear majority (68%) agreed without demur, the remainder (particularly in the Russell Group) consider that theoretical understanding is paramount.

It is generally considered that the course content specified in UK-SPEC is well aligned with these recommendations. Most respondents also point out that their courses and curriculum are constantly evolving.

12.10. ***The Report confirms the future requirement for Technical Specialists, but also identifies future demand for Multidisciplinary Systems Engineers who will fulfill the role of Integrators.***

This elucidated a mixed response due for the most part to different perceptions of 'systems engineering'. But there is widespread agreement on the need to develop engineering graduates with the multidisciplinary approach required for successful systems integration.

Universities teaching general engineering courses consider that they already achieving this, principally through embedding system theory and design in interdisciplinary project work. It is envisaged that the core curriculum could be modified to incorporate more of these activities to ensure that all students develop systems engineering skills, if necessary by displacing some in-depth technical content.

12.11. ***Given the importance of the engineer as change agent through creativity and innovation, how can these attributes be best developed in degree courses?***

There was a general consensus that creativity and innovation are best taught through design and project work (both individual and group) where students can see the opportunities and need for innovation. But it was stressed that this requires high quality facilities and case study materials.

12.12. ***Industrial experience is frequently cited as a major factor in the recruitment of new graduates.***

There was general agreement (81%) with this statement and the majority of courses (76%) already include industrial placements. Most universities (77%) also encourage a gap year either before or during the course, though this is not mandatory. While universities offering sandwich courses commented on the high industry demand for their graduates there was little support (29%) for the view that more sandwich courses are required.

It was also considered that making industrial placements a specific requirement of a degree programme would place unacceptable burdens and constraints on course administration. The majority (67%) would include more industrial experience if placements were easier to arrange. But this would require dedicated staff and a strong regional network.

12.13. ***Structured graduate training schemes are needed to support SMEs. Could the universities could expand their role to cover the initial professional development requirements?***

The universities already participate in a wide range of activities and schemes involving interaction with SMEs, such as student placements, projects and Knowledge Transfer Partnerships (KTP). Several universities have dedicated units which work in collaboration with industry and many already provide CPD courses for SMEs in their area.

While a majority of universities (56%) are prepared to consider this role (if properly funded) it is considered that much of the experience required can only be gained in industry. As such the Regional Development Agencies could play a key role in supporting these activities where needed.

13. Appendix 5

Academic Respondents

Responses were gratefully received from the following:

- Anglia Ruskin University
- Aston University
- Bath University
- Birmingham University
- Bournemouth University
- Bradford University
- Bristol University
- Brunel University
- Cambridge University
- Cardiff University
- Coventry University
- City University
- Cranfield University
- De Montfort University
- East London University
- Edinburgh University
- Exeter University
- Glamorgan University
- Glasgow University
- Heriot Watt University
- Huddersfield University
- Imperial College
- King's College London
- Lancaster University
- Leeds University
- Leicester University
- Liverpool University
- London South Bank University
- Loughborough University
- Manchester University
- Manchester Metropolitan University
- Napier University
- Newcastle University
- Northumbria University
- Nottingham University
- Oxford University
- Queen Mary, University of London
- Queen's University, Belfast
- Reading University
- Sheffield University
- Sheffield Hallam University
- Southampton University
- Staffordshire University
- Strathclyde University
- Surrey University
- Ulster University
- University College London
- University of Wales, Bangor
- Institution of Civil Engineers
- Institution of Mechanical Engineers
- Institution of Structural Engineers
- New Engineering Foundation