The Royal Academy
of Engineering

Educating engineers to drive the innovation economy

Educating engineers to drive the innovation economy

ISBN 1-903496-64-0

April 2012

Published by
The Royal Academy of Engineering
3 Carlton House Terrace
London
SW1Y 5DG
Tel 020 7766 0600

Copies of this report are available online at:
www.raeng.org.uk/innovationeconomy

Registered Charity Number: 293074

Table of contents

Acknowledgements

The Royal Academy of Engineering would like to thank the following people and organisations who have contributed material and case studies for this report:

From the University of Nottingham and Nottingham University Business School:
- Professor Martin Binks
- Professor Geoffrey Kirk RDI FREng
- Paul Kirkham
- Dr Simon Mosey

From The Royal Academy of Engineering:
- Professor Peter Goodhew FREng
- Professor Daniel Steenstra
- Professor Richard Taylor FREng

Rolls-Royce plc

Concrete Canvas Ltd

This report could not have been produced without the support and guidance of Professor Matthew Harrison and Eur Ing Ian Bowbrick at The Royal Academy of Engineering.

Foreword

The UK faces a number of challenges as it moves out of recession and towards growth. We are passing through a period of austerity, the like of which we have not experienced since the late 1940s. The most significant challenge is how to get the economy back on its feet in a sustained manner. We believe the best way for the UK to achieve this long-term financial prosperity is to increase our capability and capacity for innovation.

The UK remains home to some of the very best designers and engineers in the world, but an incomplete understanding or application of innovation processes means that many of their good ideas will go no further than the drawing board or the computer screen.

The will to succeed in the innovation arena is always very apparent when I visit schools, universities and industry – whether large-scale or SMEs. However, what the UK needs is a well-educated and entrepreneurial environment to stimulate and manage this creative flair into competitive advantage.

This report from The Royal Academy of Engineering turns 'challenge' into 'opportunity' as we explore ways in which innovative engineering skills and processes drive a sustainable economy. I am very grateful to the people and organisations contributing to the report, and I hope that their insight and enthusiasm will help and encourage many stakeholders to make the UK an innovative engineering nation.

Dr David Grant CBE FREng
Vice President, The Royal Academy of Engineering
Vice-Chancellor, Cardiff University

Executive summary

The UK economy and society as a whole are faced with complex challenges such as the budget deficit, the need for sustainable energy and the rising cost of healthcare. There is a growing realisation, by policymakers and in business, that innovation is crucial for a sustainable society. Government itself is experimenting, using the open innovation platform DotGovLabs, to build online communities to deal with these challenges. The government's report The Plan for Growth identifies four ambitions, two of which are to create a more educated workforce that is the most flexible in Europe and to make the UK the best place in Europe to start up, finance and grow a business[1]. The changes to innovation education presented in this report address both of these ambitions.

Historically the UK has produced numerous groundbreaking inventions such as the television, jet engine, hovercraft and penicillin, but has never fully realised the benefits through exploiting the markets for these discoveries. A major constraint has been the historical legacy in engineering education of studying within distinct disciplines. This has led to a focus upon incremental innovation, characterised by small changes that improve current practice. However, in order to transform the UK economy there is a growing need for more radical innovation – changes that create a new 'state of the art'.

This report takes the long view on the subject of innovation, highlighting the three major types before focusing on the radical innovation process and how this can be embedded into engineering education. The report proposes a realignment of innovation education for engineers, moving the emphasis from purely downstream improvements in productivity and efficiency towards an upstream emphasis upon creativity and transformation.

The Royal Academy of Engineering has already emphasised the need for innovation in its *Educating Engineers for the 21st Century* report to ensure that graduates are equipped to meet future challenges[2]. Its Visiting Professor schemes have a formative role to play in embodying current industrial practice in respect of innovation within university teaching. The report highlights further fundamental changes in how innovation should be taught to ensure that engineering students and professional engineers are able to fulfil their contribution to the innovation economy.

The Visiting Professor schemes should be enhanced through the embedding of radical innovation within the engineering curriculum. Engineering students should routinely work together with management, science and social science students so that they may understand radical innovation more fully and develop their skills at transforming the state of the art. This report highlights how this can be achieved via two means. First, by encouraging of students to work upon real life issues such as energy and water security, and the ageing population; second, by allowing students to consider the exploitation of novel technological breakthroughs such as hydrogen fuel cells and new applications of microwave heating.

Education initiatives which are widely regarded as effective practice are showcased so that they can be mainstreamed throughout the UK higher education sector. For instance, undergraduate modules where engineering students work with business students and industrialists to address societal problems are shown to be highly effective and scalable. Similarly, cross-disciplinary masters programmes in conjunction with entrepreneurial boot camps are shown to be effective models for engineering researchers to learn how best to commercialise novel research. Such interventions should be expanded in both scale and scope.

Recommendations

The examples given in this report highlight the opportunity facing the UK. We have a small but existing capability for radical innovation that is constrained by systemic short-term thinking. We have examples of proven methods to enhance significantly this capability in future generations of engineers. The unprecedented challenges facing the UK economy focus attention on the need for a greater radical innovation capability now and in the foreseeable future. We present the following recommendations:

To government

- Establishing and driving forward a successful innovation economy will require substantial investment from government in higher and further education. The high-quality skills and radical innovation thinking necessary for our engineers to deliver the innovation economy require corresponding innovation in the education that they receive. Government should continue to recognise engineering as a strategically important and vulnerable subject (SIVS) and increase its unit of resource to enable universities to support the necessary staff and resource-intensive activities required for radical innovation education.

To industry

- Close industry engagement in higher and further engineering education is paramount if the UK is to provide a quality an education system designed to meet the needs of a thriving innovation economy. Industry is therefore strongly encouraged to participate in activities that enrich an enhanced engineering education curriculum and offer direct experience of radical innovation. Such activities include: industrial visiting professor schemes; internships for students and industrially relevant transformative project work.

To academia

- Alongside closer engagement with industry, academics should also increase the focus of radical innovation content in engineering courses on multidisciplinary interaction. Students should work with those from other disciplines to consider, for example, societal problems and the commercial development of breakthrough technologies. This process can be expedited through the appointment of industrial visiting professors, and by deploying one or more of the techniques described in this report.

To the Engineering Council

- The professional responsibility of registrants to address radical innovation and drive the innovation economy should feature more prominently in the competency sections of the UK-SPEC.
- The UK-SPEC should be used as a driver for change to encourage education providers to incorporate more radical innovation-focus throughout the engineering curriculum.

Coda – Radical innovation thinking in context

The main report is followed by a more general scrutiny of why radical innovation is so important and how it can be encouraged in practice.

Introduction

The UK has a rich tradition of innovation and its strengths in design and engineering are recognised globally. UK engineering has been at the forefront of a vast range of innovations that have changed the world – steam engines that led to rail networks and industrialisation; jet engines that led to global travel, and the internet, connecting people and providing global access to vast amounts of information. UK innovations in medicine, such as penicillin and MRI scanning, have led to earlier diagnostics and better therapy for patients.

Today companies such as Rolls-Royce and Smith and Nephew are market leaders. Autosport Valley, the global centre for racing car development is based in the UK and international companies such as Alstom and GE have major engineering centres in the country. However, over the last 20 years an increasing focus upon short-term financial performance has led these firms to focus predominantly upon incremental innovation: the capability to develop next generation products based on customer feedback. In parallel with this shift, UK universities have developed a concomitant focus upon educating engineers primarily for developing incremental innovations.

> "This Government believes technology-based innovation will be one of the key drivers of the private sector-led economic growth that Britain so urgently needs."
>
> Rt Hon David Cameron, Prime Minister in *'Blueprint for technology'*[3]

Yet, there is a growing recognition that incremental innovation is not sufficient to deal with the grand challenges with which we are now faced, not just in industry but in wider society. The most pressing are the needs for sustainable energy and a reduction in pollution, economic stability and equality, and affordable healthcare. These big or 'complex' challenges cross national boundaries and are too complex to be undertaken by industry alone; to address them, governments need to work in partnership with industry and academia to achieve solutions[4]. Governments also need to fund the work to deal with these challenges which can only be paid for through taxation; a model that requires industry and commerce to be successful. It is interesting to note that the UK government is currently experimenting with open innovation using the web-based platform DotGovLabs Innovation Hub. This is a virtual space that enables innovation of public services by bringing together users, innovators, investors and government to shape and build radical digital solutions to social challenges[5].

> "The focus must be spurring enterprise and innovation to develop the next generation of wealth creators – high-tech companies and entrepreneurs, across all sectors."
>
> Sir James Dyson CBE FREng in *Ingenious Britain*[6]

There is a vision of a high-tech UK emerging expressed in Sir James Dyson's *Ingenious Britain* report. He argues that more innovations, and in particular, more radical innovations are required to address these complex challenges. These innovations need to work on two interrelated levels:

- Economic success – to generate the wealth and prosperity needed to fund work on the big challenges;
- Effective innovation – industry and policymakers working in partnership to address these challenges directly and develop innovative solutions

At the core of most innovations is a new technology or a new application of an existing technology. This puts engineering at the centre of innovation. Engineers have an established capability to deliver incremental innovation. Radical innovations, however, require new knowledge and skills. Building this capability therefore means changes to the way engineers are educated.

The objective of this report is to bring about changes in innovation education at both the higher and further education levels, in order to prepare engineers who can deliver radical innovations.

There is still confusion and misunderstanding about innovation which is why this report now continues by defining innovation and explaining the different types of innovation. The theoretical underpinnings of this work are considered within the coda that explores why radical innovation is so important, why it has been neglected and the challenges involved in developing radical innovations. It presents a framework for radical innovation which leads to an exploration of the position of engineering and the role of engineers in the different types of innovation.

Following the definition of innovation, the main body of the report considers exemplars of radical innovation in UK industry and academia and highlights how this activity could be expanded significantly. It concludes by discussing the implications for engineering education and other subject areas and finally presents recommendations for government, industry and academia.

Definition of innovation

Despite the topicality of innovation there is still some confusion about its definition, particularly with reference to the roles of invention and creativity. Sometimes invention and creativity are viewed as generating ideas while innovation refers to their deployment in practice as appropriate. There is a need to explore and define what innovation is in more detail.

For the last 15 years the UK government has stated that "*Innovation is the successful exploitation of a new idea*". The Department of Business Innovation & Skills has recently refined that definition to "*Innovation is the process by which new ideas are successfully exploited to create economic, social and environmental value*"[7]. This is a further sign that government recognises the importance of innovation for dealing with complex challenges. Central to both definitions is the fundamental view that innovation is about successful exploitation.

Creativity, invention, design and entrepreneurship

Innovation is related to creativity and design. Creativity is defined as the generation of new ideas which can be the result of blue skies thinking or in response to customer needs. Ideas are the raw material of innovation. An invention is the result of creativity and can be defined as a new product or process and can become an innovation when it is used and generates benefits.

Sir George Cox in the 2005 *Cox Review of Creativity in Business* describes design as '*Linking creativity and innovation. It shapes ideas to become practical and attractive propositions for users or customers. Design may be described as creativity deployed to a specific end*.'[8]

Entrepreneurship is defined as the ability to identify, evaluate and exploit new business opportunities. Being enterprising means creating or reconfiguring a business to deliver novel products or services to satisfy market demands.

Scope of innovation

This report adopts a broad definition of different types of innovation to include the following:

Product innovation – changes in products or services that an organisation offers.

Process innovation – changes in the way that products or services are created and delivered.

Position innovation – changes in the context in which products or services are introduced.

Paradigm innovation – changes in the underlying mental models and technology which frame organisations' activities, as exemplified in the development of online retailing, hybrid cars and wind turbines.

The focus of engineering education is typically upon innovations of product and process and then is constrained further by only considering the design or technical implementation of new products or services. This limited view of innovation provides a challenge for the profession to contribute towards developing the other types of innovation that contemporary society urgently requires.

Innovations in position and paradigm as well as product and process are necessary to make inroads into current unsustainable models of manufacturing, transport and energy generation and usage. This difficulty is compounded when we consider the more profound dimension of innovation – the degree of novelty.

Incremental, radical and disruptive innovation

Innovation is the process whereby change and progress happens and the seminal figure in its study is the Austrian economist and political scientist Joseph Schumpeter. He commences *The Theory of Economic Development*, published in 1912, with a description of how circular flow leads to a stationary state, unless it is interrupted by innovative activity. Schumpeter identified two different responses to changes in the business environment: an 'adaptive response' which is an adjustment of existing practice – incremental innovation; or a 'creative response' which comes from outside existing practice – radical innovation[9].

The adaptive response essentially results in incremental change whereas the creative response leads to radical change – which is often disruptive since it is likely to replace old ideas, technologies, and products. Skills and equipment become obsolete. For example, signal flags and semaphore were replaced by the electric telegraph, which in turn was replaced by wireless technology. Morse code lasted for over a century but is a mere curiosity these days. The telegram has been replaced by email or SMS. For Schumpeter, 'the creative response is an essential element in the historical process; no deterministic credo avails against this'. Schumpeter uses the word 'entrepreneur' to describe those whose actions disturb the equilibrium and are the driving force of economic development. The entrepreneur identifies and creates opportunities and acts to realise those new possibilities.

This description of the nature of change is not exclusive to economic activity – it can be seen in science. In 1962, Thomas Kuhn published *The Structure of Scientific Revolutions*, arguing that science does not progress by a simple linear accumulation of knowledge, but is characterised by periodic revolutions. 'Normal science' represents a linear progression of successful problem -solving, until the pressure of unsolved puzzles or anomalies builds up causing a 'crisis' which is resolved after a period of 'revolutionary science' which overturns some or all of the previously accepted principles[10].

The discovery of new facts and the invention of new theories mark these changes. For example, the earth-centred model of the universe was replaced by the sun-centred model. The new worldview accommodates the problems of the old worldview better and more fully, while setting a completely new array of puzzles to be solved. Kuhn describes the web of interwoven assumptions and beliefs which underlie normal science as a 'paradigm' and the revolution which overturns it as a 'paradigm shift'.

The distinction is easily summarised: incremental innovation improves – radical innovation transforms.

In the 1990s, Professor Clayton Christensen of the Harvard Business School investigated why some innovations that were radical in nature reinforced an incumbent's position in a certain market contradicted well known innovation models such as the Henderson-Clark model. In his 1997 publication *The Innovator's Dilemma*, Christensen cited the example of the disk drive industry where despite new technology in the form of architectural innovations shrinking the size of drives from 14- to 8-inches, the established manufacturers persisted with the larger disk drives. This was because their main customers, the mainframe manufacturers, were not at all interested in the smaller hard drives. Newcomers who decided to sell the smaller drives were therefore forced to look for a new market that would value the characteristics of the smaller disk drives. This they found in the manufacturers of minicomputers such as DEC and Hewlett Packard. Customer demand for minicomputers ultimately grew significantly, reaching 25% each year, while at the same time the producers of the 8-inch disk drives were able to increase their disk capacity by 40% each year. Eventually, the performance of the smaller disk drives was comparable to that of the larger drives and was sufficient to supply lower-end mainframes. The manufacturers of the larger disk drives saw their market invaded when it was too late to react and ultimately they all went out of business. This form of innovation, that creates a new market by applying a different set of values, and ultimately overtakes an existing market, Christensen termed disruptive innovation[11].

Innovation within the engineering profession

Within the engineering profession, incremental innovation is continuous and gradual change has a clear heritage. This type of innovation is responsive to problems, opportunities or trends; maintains or enhances competitive position; is lower risk; and is the most common form. Such incremental innovation typifies the majority of development work within the automotive and aerospace sectors.

By contrast, with radical innovation, creative destruction according to Schumpeter occurs where there is no apparent heritage. Creative thinking challenges paradigms, is higher risk, goes beyond competitive positioning, has the potential to impact fundamentally the way the world operates, and is less common. Radical innovation is responsible for the genesis of high-technology industries such as ICT, telecommunications, biotechnology and sustainable energy.

Due to the long product lifecycles of large-scale manufacturing-intensive industries, a pragmatic focus upon incremental innovation was warranted during the 20th century. However, the apparent and ever-growing need for radical innovation in the 21st century is severely constrained by this historical legacy.

It should be emphasised that the UK is in a potentially strong position to develop a radical innovation capability as it faces the challenge of expanding existing if somewhat isolated practice. The following sections show examples of radical innovation from UK industry and academia and recommend how such practices can be embedded more widely.

Examples of UK radical innovations

Totalcare® from Rolls-Royce: meeting the needs of key customers through radical innovation

In the mid 1990s, Rolls-Royce was in the process of updating its business and service strategy, at the centre of which was the need to change its business model. Its existing business model did not generate sufficient cash flows to justify massive R&D investments and it relied upon things 'breaking' to generate revenues from its customers through the sale of replacement spare parts, which was hardly aligned to customer needs. At the time, the aviation industry had developed to a stage where the majority of large airline operators had in place huge support infrastructures, creating multiple duplications across the supply chain, which they could no longer sustain as market pressures forced them to cut costs and focus on core business.

One major area of expense concerned the overhaul of jet engines. Despite having a total life of 20 to 25 years, a jet engine contains 10,000 parts and has to be taken out of service for a full overhaul every five years or so. A full overhaul costs several million dollars, with through-life costs as important as original purchase price. Rolls-Royce therefore set about developing their new strategy around collecting and managing data to service the aftermarket more efficiently. The result was TotalCare®, which is essentially a menu of engine-fixing and add-on services. The core elements are service integration, engine health monitoring and comprehensive engine overhaul, in addition to engine reliability improvements and Rolls-Royce-initiated specialist maintenance. Add-on services include technical records management, engine transportation, spare engine support, additional overhaul coverage and the option for the customer to initiate specialist line maintenance. The menu-driven approach and slightly different service levels across different customers, makes TotalCare® highly customised but also complex to manage. Combining the data generated from its entire product fleet with Rolls-Royce's knowledge, experience and infrastructure, these services are delivered in a planned and predicted fashion. All TotalCare® engines are monitored by the Operations Centre 24 hours a day. By being charged on a $\engine-flying-hour basis, TotalCare® makes reliability and time on wing a driver for profit for both airline and OEM.

Rolls-Royce is beginning to enhance its engine health monitoring with the intention of eradicating unscheduled repair or maintenance events. The potential impact of removing unscheduled events was seen recently during a flight from Singapore to New York when the flight was struck by lightning. Rolls-Royce's service team in Derby was able to assess the condition of the plane's engines and advise the pilot that it was safe to continue the flight, saving the airline between $1 million and $2 million in disruption costs, and highlighting the potential value of this enhancement for similar events.

Since 2000 there has been a massive growth in TotalCare®. In 2010, 65% of all in-service large engines will be covered by TotalCare®. Total management of its engines is a powerful value proposition for Rolls-Royce's customers.

Rolls-Royce developed TotalCare® as a response to a customer problem. The outcome was radical innovation of the paradigm of the company which transformed from supplying products to supplying a service. As with healthcare, there was a radical shift of emphasis from the efficiency of treatment to the effectiveness of prevention while continuing to improve both.

Concrete Canvas: commercialising a radical innovation developed at Imperial College London

Peter Brewin and Will Crawford co-founded Concrete Canvas Ltd in 2005 in order to commercialise Concrete Cloth and Concrete Canvas Shelters. Concrete Canvas, as its name suggests, can be erected like a tent and then, with the addition of water, transformed into a concrete structure. They invented the technology while studying for a postgraduate degree at Imperial College London and the Royal College of Art. The first six months following graduation were spent developing the technology and business case while putting together the seed funding. They had previously appeared on the BBC programme Dragons' Den where they were offered investment but turned it down as the equity share rate required was too high.

The initial seed funding was raised from a combination of competition prize money: they succeeded in winning more than 16 prizes from design and business plan competitions, including the Saatchi & Saatchi Award for World

Changing Ideas; an angel investor group and also a grant from the East Midlands Development Agency. The company then moved to Northampton where one of its suppliers, Walkerpack Ltd, lent the company an old factory for 14 months. During this time Concrete Canvas developed the first prototype production machine for Concrete Cloth and full-scale prototypes of the Concrete Canvas Shelters.

At the end of the 14-month period, Concrete Canvas relocated to its current site in South Wales and set about raising a second round of funding. This it achieved with a larger investment from the original angel group and grant funding from the Welsh Assembly. This enabled the company to develop the volume production systems for Concrete Cloth and Concrete Canvas Shelters and to complete the development of these products.

The first major sales were to the UK's Ministry of Defence and sales to the defence sector are still significant. However, the majority of sales are now to the private sector, with around half for export outside the European Union through a worldwide distributor network. Since starting sales the company has doubled its turnover year on year despite the challenging economic conditions. The majority of the company's sales are to customers in the construction industry who use Concrete Cloth for applications such as water management and erosion control where it has very significant advantages over incumbent technologies. Concrete Canvas works with customers to prove new applications for Concrete Cloth; for example, it was recently used underground by a large mining company and in another project it was installed by divers on a subsea pipeline. Since the material has so many potential applications, the company confidently expects to be able to maintain growth both by expanding its existing sales and by entering new markets. Concrete Canvas also continues to develop the technology with a bulletproof Concrete Cloth and a very high-performance structural fireproof material for the energy sector in development.

Concrete Canvas is an example of delivering a radical innovation from a technological breakthrough. By identifying novel market applications for a new technology, Concrete Canvas has developed its entrepreneurial capabilities to deliver a sustainable competitive advantage.

Education for innovation

In a recent report, the League of European Research Universities has recognised that one of the main innovation roles of universities is in developing 'human capital'[12]. At present, university-level education is geared towards incremental innovation; engineers do not have the opportunity to develop the skills and experience for the other types of innovation that society urgently requires.

Teaching innovation

Students need to be taught the principles of radical innovation, but it is important that they also build up practical experience through experiential learning by working on real-life projects. Just as reading a music score is not sufficient preparation for a musician to play in an orchestra, innovation cannot be taught from a book – it needs to be experienced, it needs immersion.

Dealing with complex challenges requires people with broad thinking capabilities and people with deep technology expertise who can work together in multidisciplinary teams. Innovation education needs to be based on experiential learning techniques with teams of students addressing real challenges from business or wider society. It is crucial that students work in multidisciplinary teams across departments and schools with engineering students working together with those from business, design and social sciences. The Conceive – Design – Implement – Operate (CDIO) initiative provides a good basis. CDIO is a collaboration of 70+ universities around the world, initiated by the Massachusetts Institute of Technology in the late 1990s. It provides a framework of engineering education standards, curriculum, facilities and assessment[13].

It is important that innovation is not seen as an extracurricular activity – innovation is not an option. Practical innovation workshops either regularly scheduled or as intensive boot camps have to be presented as an integral part of the curriculum.

Students need to be guided through their innovation experience and this defines the role of academic and industry tutors. Not only do such tutors need to have theoretical knowledge and practical experience, they also need to be able to facilitate the students' learning – sometimes guiding or letting things develop or providing direction.

While students will have to work on real-life challenges there are a number of practical limitations. Understanding customer needs is paramount to innovation. It is not always practical for students have to be able to interact with real customers. Simulation techniques, serious business games or online communication tools such as Skype, LinkedIn and Facebook can be used.

Simulation techniques help students to work through different scenarios and explore the consequences of their decisions in a controlled environment. A number of 'serious business' games are available both in 'board game' and interactive computer software format. SimVenture, for instance, is an online simulation of a business start-up developed by a company in York[14].

In order to make the experience real, students need dedicated work spaces and equipment. They need to interact with customers and team members and apply techniques such as observation. The facility to make concept models and rapid prototypes, while currently quite expensive, allows for quick feedback and learning.

Many of the approaches outlined in this section require significantly greater resources than conventional lecturing, but are essential if an understanding of radical innovation is to be embedded into engineering education.

Role of industry and government

In order to ensure that the challenges that students address are real, industry and government need to be involved. In addition to sponsorship and making prizes available, government, and to a larger extent, industry, should provide knowhow in developing detailed project briefs. The projects need to be structured in such a way that they are accessible to the appropriate education stage of the student and build in a role for a specialist supervisor. Stakeholders need to avail themselves at key stages of the project. In addition projects should demonstrate how the students' work is relevant and will be used in the future.

Methods of assessment

It is important that students are assessed and get feedback on all aspects of their innovation capability, including their attitude, communication skills and ability to work in teams. In addition to the traditional examination, other methods of assessment need to developed and applied.

For example, students can capture and evaluate their experiences through diaries and reports. They should also be encouraged to examine the lessons learned and reflect upon them. Team members should assess each other during innovation projects. Academics and specialists from industry should act as facilitators for group projects. During the group work they should use questioning techniques to assess each individual's understanding and use observation techniques to gauge:

- attitude
- communication
- participation and interaction

Examples of radical innovation education in the UK

Across the UK several examples of how to embed and grow radical innovation education within the engineering curriculum are evident.

Here we consider four examples:

1. The Royal Academy of Engineering Visiting Professor schemes including the Visiting Professors in Innovation.
2. The University of Nottingham Institute for Enterprise and Innovation (UNIEI) which uses large scale undergraduate modules to embed radical innovation within the engineering curriculum and cross-disciplinary Masters' programmes, in addition to extracurricular boot camps, to encourage radical innovation thinking by postgraduate engineering and science researchers.
3. A partnership between Imperial College Business School, Imperial College Engineering Faculty and the Royal College of Art encourages cross-disciplinary radical innovation thinking amongst postgraduate Masters' students in engineering.
4. The Judge Business School in Cambridge uses cross-disciplinary Masters' programmes in conjunction with innovation modules and entrepreneurial boot camps to give postgraduate engineering students a better understanding of how to exploit novel technologies.

Royal Academy of Engineering Visiting Professor schemes

The Royal Academy of Engineering Visiting Professor (VP) schemes are based on the experience-led education model. Senior engineers and industry sector experts are appointed as VPs at specific universities to enrich the engineering curriculum with the latest industrial technology and practices in order to enhance the quality and capabilities of UK engineering graduates. Six schemes have been run to date, all of which have focused on promoting a particular aspect of engineering, the fundamental discipline which underpins the wealth-creating potential of all innovations. These include: engineering design, sustainable development, integrated systems, building engineering physics, nuclear engineering and innovation.

The VP schemes have a formative role to play in incorporating current and future industrial practice into the engineering curriculum and most importantly facilitating innovation education.

Visiting Professors in Innovation

This initiative has been established to promote effective practice in the creativity-innovation-design cycle of activity and to incorporate the exposure of undergraduate and postgraduate engineering design projects and ideas to the marketplace. This approach takes forward several of the key findings of the 2005 Cox Review. At the time of writing, the scheme has VPs operating at Aston, Bath, Bristol, Brunel, Cambridge, Cranfield, Heriot-Watt, Hertfordshire, Hull, Leicester, Liverpool, London South Bank, Loughborough, Northumbria, Nottingham, Plymouth, Queen Mary, RCA/Imperial College, Sheffield, Strathclyde, University College London and Warwick universities. VPs on this scheme are innovation practitioners from sectors such as aerospace, automotive and healthcare. This scheme provides an excellent platform to embed the findings in this report and the scheme should be expanded in universities across the UK. Furthermore the Academy has set up Enterprise Fellowships to stimulate innovation in universities. Entrepreneurial researchers receive funding and business training to build a commercial enterprise at a UK university.

Teaching radical innovation to undergraduate students in the UK

The University of Nottingham has one of the longest-standing traditions of radical innovation education in the UK. Central to this was the creation of the University of Nottingham Institute for Enterprise and Innovation (UNIEI) in 1999, which pioneered radical innovation programmes for undergraduate and Masters' level engineering students.

In the subsequent decade UNIEI created 11 new Masters' programmes, which bridged disparate disciplines and delivered radical innovation modules to undergraduates, postgraduates, MBA students and executives from the public and private sectors[15].

A key breakthrough at UNIEI has been the demonstration that effective radical innovation education can be delivered to large numbers of undergraduates. Engineering students are able to choose optional modules using this scalable approach throughout each year of their studies. In the first year they can take part in the Entrepreneurship and Business module. Here they study in conjunction with business students and they are encouraged to identify a sustainability-related problem that is not currently addressed. They then work together with mentors from the business community to develop novel business solutions to those societal problems. This culminates in a poster presentation where they 'pitch' their ideas to expert assessors. In the academic year 2009-10 this module was completed by over 800 students in the UK, 600 students at University of Nottingham Ningbo Campus in China and 350 students in Malaysia.

Final year engineering students face a different challenge in the Science, Technology and Business module. Here they work with students from science, social science and humanities faculties. Together they choose a novel invention and consider how best to take this to market. For instance, one breakthrough technology that students have considered is 'anti-noise'. This is the use of sound waves created deliberately to cancel out unwanted noise in the environment. With a little imagination, students have taken this concept forward, from noise-cancelling headphones for commuters to ideas that could revolutionise our working and leisure environments. They have created a world where cities have quiet zones in parks, despite heavy traffic passing close by. Students have proposed building a 'silent house' near Heathrow where aircraft noise was a thing of the past. This module demonstrates the process of radical innovation to the students and allows them to realise the health and economic benefits that radical innovation can bring.

Teaching radical innovation to postgraduate researchers in the UK

Imperial College London has a long tradition of cross-disciplinary working between the business school and the engineering faculty. This formed the cornerstone of a more radical model with the formation of Design London in 2007. Here the business school and the engineering faculty work together with the Royal College of Art to offer a radical innovation education to engineering Masters students.

The core offer from Design London is a fellowship scheme for Masters of Engineering students and postgraduate researchers which enable them to study with MBA students to learn how to transform their ideas into new business models more effectively. Together they explore the commercial potential of new science- or technology-based inventions. This culminates in a business-style presentation where the ideas are evaluated by potential investors.

However, the experience does not end there. Selected ideas are taken forward to an entrepreneurial boot camp. Here teams are formed bringing together engineers, designers and businesspeople and they spend 10 weeks together honing their ideas. To date, eight ventures have attracted investment from this process with radical ideas generated to address different societal issues. For example, one venture is developing a waterless sanitation system that transforms human waste into power[16].

At the Judge Business School the scalability of cross-disciplinary Masters' education is demonstrated through their six MPhil degrees in the areas of Advanced Chemical Engineering, Bioscience Enterprise, Computational Biology, Engineering for Sustainable Development, Micro- and Nano- Technology Enterprise, and Technology Policy. These courses are all served by a central programme in the Management of Technology and Innovation (MTI). MTI shows engineering and science students how new technologies can reach the marketplace more effectively. In addition to taught modules, all students have to work on a real industrial problem as part of a consultancy project.

The impact of these programmes is impressive: between 2006 and 2008, students from these programmes won the Cambridge University Entrepreneurs programme. By the end of the 2005-06 academic year, 381 students had worked on team projects with over 60 companies from the private and public sectors.

In a similar vein, UNIEI has demonstrated that extracurricular interventions can also deliver scalable benefits to postgraduate researchers. A series of programmes is underway based upon the entrepreneurial 'boot camp' model that underpins the Biotechnology Young Entrepreneurs Scheme (YES), one of the longest-running researcher training initiatives in Europe. This is an innovative competition to raise awareness of the commercialisation of bioscience ideas among postgraduate students and postdoctoral researchers.

The competition is residential and runs over three days. The participants, in teams of five, attend presentations from leading figures in industry on different aspects of technology transfer and the commercialisation of research. This knowledge is then used to prepare an oral business plan presentation based upon potentially breakthrough research. Each team member assumes a different role within a hypothetical start-up company and works together with industry mentors to develop a business plan. This culminates in a presentation made on the final day to a panel of equity investors, intellectual property and business development professionals. The winning teams go through to a grand final in London where a variety of research council and industry sponsored prizes are awarded.

Between 2005 and 2009, 1,550 researchers took part and, according to a number of sources of evidence, the competition has made a significant impact upon their innovative skills and future career destinations[17].

In 2005, a review of the competition found that researchers who were past participants of the scheme had raised over £5 million of equity investment for their new ventures. Moreover 12% of the group were working in technology transfer or intellectual property management roles. Clearly a significant number within this group have made entrepreneurial changes to their careers, moving into areas that are not traditionally pursued by academic researchers.

A number of other similar schemes have been launched to build upon the success of this model in order to deliver the learning outcomes to researchers from other disciplines. In 2005, the Environment YES was launched to encourage environmental scientists and engineers to understand how best to commercialise novel research within the domain of environmental measurement and control. This was followed in 2008 with the launch of Sustainability YES and Engineering YES, where engineering students work together with scientists and business students to see how novel technologies can address issues such as the lack of a sustainable water supply and the need for low carbon energy distribution and usage.

These schemes all share a common format in focusing students' attention on the pre-concept innovation challenges of developing novel business ideas from breakthrough technologies. Participants consistently report positive learning outcomes and significant impacts upon their career aspirations. However, the latter schemes of Engineering YES and Sustainability YES are still in their infancy with only two universities participating in 2010. Clearly, with appropriate support and leadership, these schemes can be scaled up to mirror or even surpass the success and impact of the Biotechnology YES.

Coda – Radical innovation thinking in context

The current state – an increasing need for radical innovation

To conclude and underpin the preceeding arguments, it is important to recognize the role of radical innovation thinking more generally.

Social challenges

The UK economy faces challenges of an unprecedented nature. Trends such as the lack of a sustainable energy supply, an ageing population, the increasing cost of healthcare and public services, and the shift towards a knowledge-based economy are in urgent need of redress.

There have been many philosophers and thinkers who have predicted the imminent downfall of the human race due to overpopulation, the depletion of vital resources, collapse of the financial system and more recently, climate change.

"…I say, that the power of population is indefinitely greater than the power in the earth to produce subsistence for man."

This argument is as important today as when it was first articulated in 1798 by Thomas Malthus in *An Essay on the Principle of Population*[18]. He was not the first person to forecast trouble. Around 2000 years earlier the Chinese philosopher Han Fei-Tzu had made the same point.

Population is now rising extremely quickly, faster probably than either Malthus or Fei-Tzu predicted and doubts are still being raised as to whether there is a limit to the technical solutions possible.

The science of climate change has intensified the debate. In 2006 the *Stern Review on the Economics of Climate Change* argued that strong, early action is essential to obviate the consequences of climate change[19]. The extremes of the argument can be represented thus:

The pessimistic view is that of scientist James Lovelock[20] who states that: "…billions of us will die and the few breeding pairs of people that survive will be in the Arctic where the climate remains tolerable."

The optimistic view is that of the cornucopians who follow Julian Simon's 1996 mind-boggling vision of resources in *Ultimate Resource 2*[21]: "the more we use, the better off we become – and there's no practical limit to improving our lot forever. Indeed, throughout history, new tools and new knowledge have made resources easier and easier to obtain. Our growing ability to create new resources has more than made up for temporary setbacks due to local resource exhaustion, pollution, population growth, and so on."

Whichever view proves to be correct it is indisputable that, currently, mankind survives, and for many people things have never been better in terms of health, life expectancy and material possessions. This is because problems and opportunities have been recognised, and creative solutions have been generated and implemented in the process of innovation.

Commercial challenges – uncertainty in the fundamentals

The financial malaise towards the end of the first decade of the 21st century was not predicted or expected by those whose job it was to do so. Prevailing micro- and macroeconomic theories appear to have failed to anticipate the causes of the crises and thus reduce their impact. Stock exchanges did not begin to take account of the obvious impending nature of collapse. Alongside the frailty of financial markets, there is a more fundamental question about our understanding of micro- and macroeconomics in terms of the financial sector and the extent to which we are able to deploy policies and strategies to meet the new challenges with any great confidence. These failures have to be recognised and there has to be an acceptance of the alarming possibility that change cannot be predicted from within; the history of innovation suggests that has certainly been the case in the past.

The innovation challenge for UK plc

Despite this background, the UK is in a unique position to address these issues due to the opportunities inherent in new technological breakthroughs from industry and universities. The UK leads the world in areas such as nanotechnology, fuel cells, medical devices and power distribution, yet it would appear to lack the radical innovation capability to match these breakthroughs to the needs of society and move the economy towards one which gains more value from technology.

Future needs – applying a process model of radical innovation

Avoiding common innovation errors

To avoid the future foretold by the doom-mongers, the first step is to identify these game-changing, paradigm-shifting innovations. At the moment the pace of scientific and industrial change is increasing at the same velocity that problems keep appearing. There doesn't seem to be a shortage of ideas – how 'good' some of these ideas are is a different matter. A great deal of time and effort is expended upon ideas which never get off the ground or make a significant impact.

The American entrepreneur John Osher[22] listed 17 mistakes entrepreneurs need not make. Mistake number one is failing to spend enough time researching the business idea to see if it is viable: "This is really the most important mistake of all. They say 9 [out] of 10 entrepreneurs fail because they're undercapitalized or have the wrong people. I say 9 [out] of 10 people fail because their original concept is not viable. They want to be in business so much that they often don't do the work they need to do ahead of time, so everything they do is doomed. They can be very talented, do everything else right, and fail because they have ideas that are flawed."

This sort of mistake is not confined to businessmen: one of the greatest engineers and inventors of his own or any other time, Nikola Tesla, noticed: "Some people, the moment they have a device to construct or any piece of work to perform, rush at it without adequate preparation, and immediately become engrossed in details, instead of the central idea. They may get results, but they sacrifice quality"[23].

Therefore, rather than jumping to conclusions there is a need to engender an approach to innovation that allows time and consideration to understand the issues. Such an approach should increase the probability of identifying inventions with the potential for radical innovation and the paradigm shifts necessary to continue economic development[24].

A rational process of radical innovation

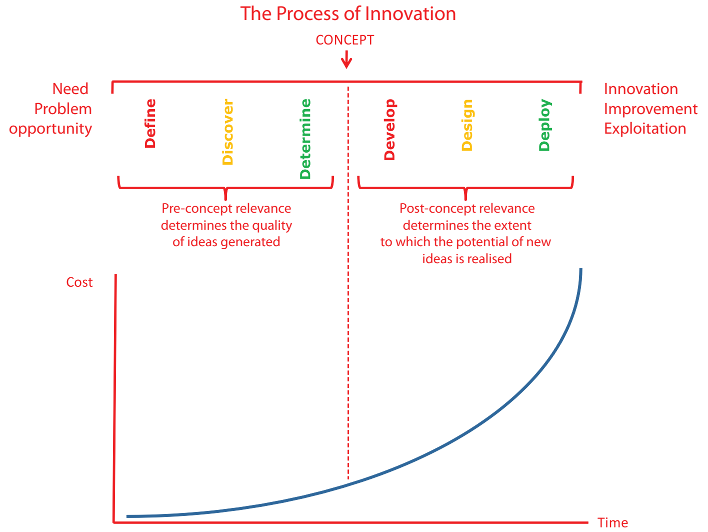
In a perfect and rational world, the response to a newly recognised problem would take the following course, were time available and urgency not an issue: significant attention would be focused initially from all viewpoints on defining the nature, impact and root cause or causes of the problem concerned. The root cause or that considered to be of highest priority would then be addressed in terms of possible solutions.

In this perfect rational world it would be important to consider the widest possible range of solutions, allowing the introduction of ideas and possibilities far beyond those that would arise from within the existing paradigm of consideration. The purposeful discovery of non-obvious solutions and insights would be the objective of this application of divergent thinking and solution generation. Having generated many thoughts and ideas out with the normal confines of practicality or realism or viability a return to more analytical thinking would be adopted.

The mass of free-thinking ideas and observations would then be sorted and sifted and combined in many different ways in pursuit of the most effective, efficient and practical solution. It is only at this point that the proposed concept for solving the problem emerges.

In our perfect rational world this concept would then be subjected to further analysis and development in the light of prototyping, market research and competitor analysis. These 'post-concept' activities will determine the eventual design of the solution which is then deployed as appropriate. This continuum of innovation can be seen in the figure below.

The ingenuity creative problem solving process: a quick start guide



Investment in innovation is most cost-effective at the pre-concept stage

Given the time and capability to adopt the perfect and rational world approach, the case for its application in practice is compelling. We are often encouraged to avoid jumping to conclusions and to make sure that we have considered all the options. This approach ensures that the solutions invented to address incoming problems are of the highest quality and, therefore, have the greatest potential for successful effective and efficient innovation.
This approach would also ensure that potential errors and suboptimal aspects of considered solutions are anticipated earlier in the process, thus incurring lower levels of cost in terms of rectifying them.

Mistakes identified prior to solution selection can be rectified at much lower cost than those detected after investment in prototyping and market research. Innovation that refers to the deployment of concepts invented and generated in this way is likely to be more persuasive to potential investors than that arising from less-rigorous and more-limited consideration. The role of pre-concept innovation analysis is now more significant than ever due to the prevailing uncertainly in financial markets.

Attracting investment funding for radical innovation is often problematic. This is due to the novel, unfamiliar and often unpredictable nature of the ideas involved. Attracting finance in the prevailing markets is more problematic still and requires the case for investment to be as strong and well-argued as possible. If we neglect pre-concept considerations there is a risk of defaulting to inferior ideas which have less persuasive cases for investment.

Dealing with financial uncertainty and short-termism

Evidence of the dangers of neglecting pre-concept innovation can be seen within the financial markets. Catastrophic failures in the operation of financial markets have created one of the worst environments for long-term investment in radical innovation since the Great Depression of the 1930s. It would appear that the innovation of new concepts such as derivatives was not subjected to any kind of rigorous analysis of consequences, thus enabling the proliferation of packages of risk with little or no transparency. Mortgages sold on a commission basis in one country could become part of a package to be sold on to a purchaser with no knowledge of the likelihood of repayments being sustained.

Robust financial systems were not applied and a new 'paradigm' was created through the innovation of fundamentally flawed financial products and instruments. Investments in radical innovation require, to some extent by definition, a leap of faith in terms of future potential because there are no existing data on which to measure reliably the risks involved. The uncertainty in financial markets created by the banking crisis may only serve to reinforce the natural resistance to the deployment of radical innovation in practice, due to a lack of investment funding.

Avoiding the pressure to default to quick fixes

Most individuals, when confronted by a new problem, will seek a swift solution. Problems and their counterparts in unmet needs and opportunities are uncomfortable. Apparent solutions alleviate that discomfort and reassure with a sense of achievement. The same basic pressures occur in organisations when confronting new and potentially threatening issues. A chief executive when confronting the board may simply ask the engineering director to provide a rapid response in terms of how a solution is to be achieved. A measured response by that director in terms of identifying root causes, drawing solutions from different domains and exploring all realistic and some unrealistic alternatives is unlikely to be considered acceptable and may be judged to reflect indecision.

Individuals and organisations are strongly tempted to jump across those pre-concept innovation activities of problem definition, solution generation and solution selection in favour of a quick fix. The 'fix' will probably refer to solutions from the past used to address similar challenges or those adopted by others, providing the reassurance of a pack mentality devoid of original thought. Incremental innovation will tend naturally to prevail over more radical solutions.

Non-obvious solutions do not come out of 'thin air'. They rarely occur through pure chance although 'serendipity' may play a part. In some instances, the resources made available to facilitate the pursuit of non-obvious solutions are bountiful. Former President John F Kennedy's pledge to land a man on the moon before the end of the 1960s was achieved in part due to the vast resources made available to NASA. In more usual circumstances, resources are constrained and time itself may appear in short supply. Knowing how to encourage rigorous pre-concept innovation activities does not correspond to their ready adoption and enthusiastic application in practice. Approaches such as the radical innovation process described above are not difficult to communicate, but their value may be more difficult to appreciate despite the ready availability of examples.

International examples of encouraging radical innovation

The increased need for radical innovation has been recognised and encouraged by a variety of government bodies, multinational corporations and higher education institutions across the world. The government of Singapore, for example, has shown a sustained strategic intent to build a knowledge-based economy through research and development excellence. Firms such as Hewlett Packard/Compaq, General Electric, Philips and Siemens have all established design, research and development centres in Singapore to capitalise upon this emphasis[25].

Central to the success of the region is the policy aim of providing education and training for 'technologically savvy' managers. Consequently, the Singapore government has invested in a series of cross-disciplinary research institutes and Masters and PhD programmes to educate scientists and engineers to manage the exploitation of high-technology products, services and new businesses.

A similar pattern is seen within international universities. An exemplary case from Georgia Tech in the USA has been funded for the last 10 years by the National Science Foundation to encourage the transfer of radical innovations across businesses or from academia to industry. The TI:GER programme is a two-year certified course designed to help move breakthrough research to market. Throughout the course science and engineering doctoral students collaborate with MBA and legal students to consider the technical, business and legal factors that will influence the potential market application of their research.

Since 2002, 190 students have participated in the programme. A recent review concluded that the course had a significant and positive impact upon the participants' ability to perform within an innovation-intensive business environment[26].

These examples show that despite the all pervading gloom there are grounds for optimism: the concept of 'Peak Oil' is well known; the concept of 'Peak Water' is gaining currency, but it would be a very dismal person indeed who would predict 'Peak Innovation'.

Appendix 1

The Royal Academy of Engineering's Industrial Visiting Professors and Visiting Teaching Fellows congregated for their most recent biennial conference at the Aston Business School in September 2011. The purpose of the conference was to address the question ***What can we do educationally to make students more innovation minded?***

Below is a summary of the main points raised during the various interactive and plenary sessions.

- Universities must ***create a culture of innovation*** – students will perform better if they see their university practicing what they preach.
- Universities must make available ***facilities*** for students to experiment and allow them to try out their own ideas; failure should be looked upon as a learning experience.
- Universities should promote ***multidisciplinary team working*** involving engineering students of all disciplines, in addition to working with business school students.
- Innovation is best instilled in students through a combination of permanent faculty who teach students the ***core engineering material*** and industrial practitioners in an Industrial Visiting Professor or Visiting Teaching Fellow capacity who show students how to apply this knowledge to develop ***critical problem solving skills***.
- Industrial Visiting Professors and Visiting Teaching Fellows can inject innovation-focused ***industrial methodologies, real-life problems and inspiring projects*** into the student learning experience. In addition they can also facilitate guest lectures by industrial leaders and inspirational speakers.
- Industrial Visiting Professors and Visiting Teaching Fellows have an important role to play as ***Change Agents*** in making universities more innovation-facing. They can overcome obstacles of culture within universities through their standing and experience.
- The smart way to teach innovation is by ***implicit rather than by explicit means***; devising and teaching a module on innovation should be avoided in favour of ***supplementing*** the teaching on all course modules with innovation-focused material. This avoids the need to omit or replace existing curriculum material and the inherent challenge in getting new courses accredited.
- Activities such as the Academy-organised ***Innovation Hothouse***, Airbus' Global Competition and other role-play and business simulations were seen as important in allowing students to try out their ideas under real-life conditions.

References

1. HM Treasury. (2011). *HM Treasury Plan for Growth*. [Online] March 2011. Available from: ***cdn.hm-treasury.gov.uk/2011budget_growth.pdf*** [accessed 7 January 2012]
2. RAEng, 2007. *Educating Engineers for the 21st Century*. The Royal Academy of Engineering
3. BIS, 2010. *Blueprint for Technology*. Department for Business, Innovation and Skills
4. Rittell, H. & Webber, M. (1973). Dilemmas in general theory of planning. *Policy Sciences*. 4 p. 155-169
5. Cabinet Office. (2011). *Innovation Hub*. [Online] September 2010. Available from ***dotgovlabs.direct.gov.uk*** [accessed 7 January 2012]
6. Dyson, J. (2010). *Ingenious Britain*. [On-line] May 2010. Available from: ***www.conservatives.com/News/News_stories/2010/03/Dyson_sets_out_plans_to_boost_high-tech_industry.aspx*** [accessed 7 January 2012]
7. BIS. (2010). *Blueprint for technology*. [Online] November 2010. Available from: ***www.bis.gov.uk/policies/innovation*** [accessed 28 June 2011]
8. H M Treasury, 2005. *Cox Review of Creativity in Business*. H M Treasury
9. Schumpeter, J. A. (1912). *The Theory of Economic Development: an enquiry into profits, capital, credit, interest and the business cycle.* Leipzig: Duncker and Humbolt
10. Kuhn, T. S. (1962). *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press
11. Christensen, C. M. (1997). *The Innovators Dilemma*. Boston: Harvard Business School Press
12. Boulton, G., Lucas, C. (2008). *What are universities for?* League of European Research Universities
13. CDIO. (2010). *The CDIO Initiative*. [Online] January 2009. Available from ***www.cdio.org*** [accessed 7 January 2012]
14. Venture Simulation. (2011). *SimVenture*. [Online] January 2011. Available from ***www.simventure.co.uk*** [accessed 1 December 2011]
15. Binks, M., Starkey, K., Mahon, C. (2006). Entrepreneurship Education and the Business School. *Technology Analysis and Strategic Management*. 18 (4)
16. The Design Council, 2010. *Multidisciplinary design education in the UK; Five Case Studies*. The Design Council
17. Webb, D. (2010). *Evaluation of Biotechnology YES*: Final Report. DTZ Consultants

18. Malthus, T. R. (1798). *An Essay on the Principle of Population*. London: J Johnson

19. Cabinet Office, 2006. *Stern review on the economics of climate change*. Cabinet Office

20. Lovelock, J (2006). The earth is about to catch a morbid fever that may last as long as 100,000 years. *The Independent*. 16 January. Available from: ***www.independent.co.uk***. [Accessed 13 December 2010]

21. Simon, J. L. (1996). *The Ultimate Resource 2*. Princeton: Princeton University Press

22. Henricks, M. (2004). What not to do: a seasoned entrepreneur reveals the 17 most common mistakes start-ups make and how to avoid them, plus the five things you must do to ensure success. *The Entrepreneur* [On-line] 32 (2). Available from: ***www.entrepreneur.com.*** [Accessed 13 December 2010]

23. Wisehart, M. K. (1921). Making your imagination work for you. *The American*

24. Kirkham, P., Mosey, S., Binks, M. (2009). *Ingenuity in Practice: A guide for clear thinking*. Nottingham University Business School.

25. Hang, C., Ang, M., Wong, P. (2009). Technology Management Educational Initiatives in Asia. *Academy of Management Learning and Education*. 8(3) p. 444-456

26. Thursby, M., Fuller, A., Thursby, J. (2009). An Integrated Approach to Educating Professionals for Careers in Innovation. *Academy of Management Learning and Education*. 8(3) p. 389-406

The Royal Academy of Engineering

As the UK's national academy for engineering, we bring together the most successful and talented engineers from across the engineering sectors for a shared purpose: to advance and promote excellence in engineering. We provide analysis and policy support to promote the UK's role as a great place from which to do business. We take a lead on engineering education and we invest in the UK's world class research base to underpin innovation. We work to improve public awareness and understanding of engineering. We are a national academy with a global outlook and use our international partnerships to ensure that the UK benefits from international networks, expertise and investment.

The Academy's work programmes are driven by four strategic challenges, each of which provides a key contribution to a strong and vibrant engineering sector and to the health and wealth of society.

Drive faster and more balanced economic growth

The strategic challenge is to improve the capacity of UK entrepreneurs and enterprises to create innovative products and services, increase wealth and employment and rebalance the economy in favour of productive industry.

Lead the profession

The strategic challenge is to harness the collective expertise, energy and capacity of the engineering profession to enhance the UK's economic and social development .

Foster better education and skills

The strategic challenge is to create a system of engineering education and training that satisfies the aspirations of young people while delivering the high calibre engineers and technicians that businesses need.

Promote engineering at the heart of society

The strategic challenge is to improve public understanding of engineering, increase awareness of how engineering impacts on lives and increase public recognition for our most talented engineers.

The Royal Academy of Engineering promotes excellence in the science, art and practice of engineering.

Registered charity number 293074

The Royal Academy of Engineering
3 Carlton House Terrace, London SW1Y 5DG

Tel: 020 7766 0600 Fax: 020 7930 1549
www.raeng.org.uk