The Royal Academy of Engineering

The US National Academy of Engineering “Grand Challenges” project

Response on behalf of The Royal Academy of Engineering

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The UK Royal Academy of Engineering

Some engineering ideas for the 21st century

Contribution to the US National Academy of Engineering's "Grand Challenges" project

Introduction

The UK Royal Academy of Engineering is pleased to be able to contribute to the US National Academy of Engineering "Grand Challenges" project. This submission has been developed on the basis of input from a wide range of Academy Fellows and Academy-sponsored researchers. Fellows and sponsored researchers were initially invited to contribute to the "Grand Challenges" project, either by sending their ideas to the Academy, or by submitting them directly to the NAE. A Working Group of Fellows and sponsored researchers from a range of sectors and backgrounds, chaired by Sir Duncan Michael FREng, then reviewed the suggestions received and selected around a dozen ideas using, as a starting point, the criteria listed below:

1. intellectual life: must span a sufficiently long period of time;
2. potential & impact: must be likely to have an effect;
3. no inhibition of subject (broad vision & creativity); and
4. potential for UK contribution to the realisation of challenges.

In selecting the challenges to be included in the Academy's submission to the NAE, the Working Group sought to incorporate ideas that spanned different themes and focussed on both contextual and technical challenges. The final selection is, therefore, not intended to constitute a comprehensive or definitive list of the most important challenges facing engineers in the 21st century. Instead, it represents a collection of ideas which illustrate the breadth and complexity of the greatest challenges of the next 100 years for which engineering-led solutions must be developed.

1) FOUNDATIONS OF ENGINEERING

- **An aspirational ethos**

Despite the undeniable achievements of modern engineering, we must always remember that engineers' primary objective is the promotion of the quality of human life. ***The challenge for us is to develop an aspirational ethical foundation in our profession and to redress the present imbalanced prioritisation in engineering of technical ingenuity over helping people.*** Our attitude should be: "here I am, how can I help you?". This entails taking an active role in considering the ethical implications of our work, e.g. in regard to the development of weapons technology, inherently wasteful products or systems that actively exclude sections of society. Achieving this objective is likely to involve building an ethical foundation into education and developing/promoting role models.

- **Matching education to the engineering world**

The challenge here is to adjust engineering education to the engineering world and to prepare young engineers for it. Many students choose to study engineering because they wish to learn the skills and competencies, and to acquire the knowledge, that will allow them to 'make a difference'. However, education is lagging behind in adapting to the evolution of engineering and graduates are increasingly encountering difficulties in approaching real life challenges. For instance, very few university courses teach recycling, teaching by studio methods is very rare and teaching multidisciplinarity as a concept non-existent. Another consequence of this mismatch is the lack of opportunity for students to be shown what engineering can do for society and for the planet (large scale engineering challenges).

Along with being shown "what" engineering can do to address global problems, students also need to be involved in a debate about the "how". New models (including so-called "open innovation") for effective working and developing trust amongst high calibre professionals can be developed to drive radical change.

Another educational challenge for us is to engage more effectively with the public. In the UK, engineering tends to be perceived as a technical discipline and therefore less "noble" than medicine or law for example. Despite the critical contribution of engineering to the development of industrialised countries (and its enormous potential for addressing key issues in developing countries), it is often the case that its achievements and change effects are overlooked or taken for granted. Hence a lack of interest and appreciation of engineering among the young and the public in general. We have a duty to engage with the potential users of our work as well as with new generations if our work is to inspire and to be recognised and valued. The modern world poses many complex and diverse challenges that only we can address.

2) ENERGY

- **Supply of affordable and sustainable energy**

Useful energy is a precious commodity and as such its availability within a region is dependent upon the purchasing power of that region. Hence, supply of energy is variable around the world, ranging from constant and secure to very scarce and intermittent provision. ***The challenge for us is to ensure that energy is widely available (cheap) AND sustainable.*** Notwithstanding that addressing energy supply is a challenge that involves factors other than engineering, it cannot be tackled without taking into account sustainability, and we engineers, more than any other profession, can make a positive difference in this context. A world-wide co-ordinated engineering, scientific and political effort is required to increase access to affordable and sustainable energy in all aspects of our existence (housing, transportation, industry). This is likely to require major innovation as well as the application of existing technologies. For instance, there may be significant benefit in exploring novel ways for exploiting the natural potential energies of the earth. Furthermore, since the effort is likely to include reliance on nuclear power, a truly sustainable solution to nuclear waste disposal must also be found, as it must for the waste already inevitable in its creation.

- **Smart use of energy**

Because of its easy accessibility and availability in developed countries, energy is often misused. A wholesale and drastic reassessment of the way in which we use energy is needed. In particular, ***our challenge is to closely examine circumstances under which information technologies might significantly reduce or even remove the need for energy expenditure***. Furthermore, we have a duty ***to engage with the public and raise its awareness of best practices with regard to optimisation (and perhaps minimisation) of energy use***.

3) ENVIRONMENT

- **Infrastructure**

Global infrastructure, including transport, water, sewage and electricity distribution systems need renewal in a manner that is cost effective, timely and which causes minimum impact on current living standards. This is a particular problem in our major cities. ***The challenge is for us to adopt a holistic approach which will involve the management of complex infrastructural networks and communication systems.*** Engineers will be instrumental in designing and implementing this.

- **Climate change**

Climate change is global in nature. The consequences of climate change do not stand in isolation and need to be treated as part of a wider debate on energy, sustainability, health and wellbeing, ethics and the legacy we leave our children. So, what can engineers do? How can they help the responses to climate change? ***One global challenge that we can tackle is to achieve an agreed position on the potential of our many energy sources and the likely technical changes through the next 30 years (e.g. wave energy and nuclear fusion). Achievement of this objective will require us to join forces with other professions (e.g. scientists, economists etc.) and policy makers*** and the outcome will be essential to finding solutions to related issues discussed above such as supply, affordability and sustainability.

4) BRAIN SCIENCE

- **Understanding the brain**

The human brain is the most complex organ. Unsurprisingly, we still lack enough understanding of its principles of operation to have insight into normal brain functions but also, and most importantly, to prevent, cure and treat several life threatening or severely impairing brain conditions and diseases. ***The challenge for us is to address the complexity of the brain as a problem of reverse engineering*** to complement the efforts of neuroscientists in addressing the complexity of the human brain. Reverse engineering is the process of “understanding by building and design” the architecture of brain and mind. This will, in turn, help us to engineer more intelligent machines.

- **Human level computing**

Computing in the last few decades has evolved to a degree that simply was not envisaged 50 years ago. In 1965, Gordon Moore correctly predicted that the number of transistors on a chip would double about every two years. As processing power continues to increase, computing will play a key part in optimising the use of physical resources and ultimately, in some cases, their substitution by the digital world. Scientists and engineers are inspired by the unique and highly intelligent outcome of human brain processing. However, the complexity of the human brain, the (often plastic) interactions of its different modules, and the interplay between cognitive and emotional functions make emulation a huge challenge. Such complexity is what computer scientists and engineers will have to understand and tackle. Achieving this is likely to require reverse engineering. However, ***the challenge for engineers is*** not to create an artificial version of the human brain but ***to design and build computers that can deal with the complexity and variability that our brains are capable of handling without apparent effort as well as those tasks that challenge human intelligence***. For instance, we humans spend much of our mental efforts trying to make optimal strategic decisions, carry out complex predictions and plan major national or corporate policies. However, we have clearly reached the limits of human capability in many cases and artificial aids, such as intelligent computers, are needed to make up for human limitations. In particular, ***a challenge for engineers is to develop a new generation of computers capable of advanced pattern recognition to be used in the decision making process***.

5) HEALTH

- **Inside-out surgery**

Conventional surgery is usually very invasive and often causes trauma to healthy organs and increases the risk of severe infections. In order to minimise the damage and risks associated with it ***the challenge that biomedical engineers are faced with is to develop surgical devices capable of destroying, repairing and replacing individual defective cells and bio-molecules from within the body***. Life expectancy in developed countries is increasing on a daily basis; however, the quality of the extra time gained must also be considered in parallel. Inside-out surgery would benefit the patient population in general but it would be of significant assistance to elderly patients and, to some extent, children, for whom invasive surgery is often a very traumatic and risky procedure.

- **Large scale vaccine production (to prevent pandemics)**

Pandemics act to create mass destruction and are, therefore, very important global health issues. Even when a vaccine has been identified, producing sufficient quantities of the drug in a short length of time to stop the disease from spreading can be challenging. ***The challenge that we face here is to ensure that large scale production techniques and facilities for effective, rapid and cheap vaccine manufacturing are available and fully functional when needed in developing as much as developed countries***.

- **Potable water**

In industrialised countries the availability of clean water is often taken for granted and its importance as a global health issue overlooked. However, in a global health context potable water is one of the most urgent issues. Furthermore, climate change could make this problem more acute and access to water is likely to become a source of conflict in an ever more water-constrained world. Hence, we are faced with ***the challenge of ensuring availability of clean water worldwide, including in less developed and overpopulated regions, as well as providing the infrastructure for its uniform distribution.*** Issues such as conservation, reuse and land management also need addressing if sustainable and effective solutions are to be found.

6) DIGITAL WORLD

- **Managing knowledge**

The internet and the world wide web are extraordinary commodities enabling real-time access to, and distribution of, information: a reality that just a few decades ago seemed implausible. The amount of knowledge available on the internet is currently increasing at an exponential rate and ***a challenge for us will be to find ways to manage information load and to prevent the virtual space from becoming chaotic and redundant***.

The impact of engineers and their ability to “make a difference” depend, to an extent, on their capacity to optimize the use of knowledge. This requires an outward looking attitude, which is often difficult to find within the commercial and intellectual property constraints of the private sector. ***The challenge for us is to adopt better working practices that encourage and reward the genuine exchange of valuable information***. As mentioned in the education section (1), models of open innovation, for example, are being introduced to drive radical change. These models are aimed at managing and optimising the use of knowledge and could also improve the management of other sets of information, such as Intellectual Property Rights.

- **Transition to cyberspace market**

Business transactions at all levels, ranging from stock exchange deals to eBay purchases, are increasingly being dealt with electronically. As a consequence of this, a significant percentage of wealth is being created in the virtual domain. The recent press has envisaged a time (not a very distant future) when coins and notes will no longer exist, replaced entirely by virtual currency. A transition to the cyberspace market can be seen as a natural development within the context of a knowledge economy. However, if this is to become a commodity for the public as a whole, ***engineers have a key role to play in ensuring that the transition occurs in an informed and intelligent manner. A second challenge for us is to ascertain that the knowledge, skills and competencies required to enable the transition are developed and nurtured at all levels ensuring that a hostile “underclass” does not evolve for lack of access to this new world.***

Furthermore, ***as the cyberspace market would not be of much use unless it were global, the challenge for us is to provide developing countries with the opportunities to benefit from it.*** This needs to be done while also optimising the use of Information Communication Technology.

Although the transition to a cyberspace market is desirable and probably inevitable, other challenges that come with it require careful consideration. Engineering and technology can be used with malign intention and we have a responsibility to use our skills to ensure that opportunities to do harm are minimised. In a society where information on many aspects of people’s lives is acquired and stored, privacy, anonymisation and security become paramount. Systems for the protection of data and for preventing fraud (stolen identity), and contingency plans for any major break down of virtual systems (either accidental or deliberate) should be carefully designed and implemented in line with robust regulations and laws***. Engineers do have a key role to play in ensuring that regulatory and legal frameworks are fit for purpose*** (for example to address intellectual property rights).

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