The Role of the Professional Engineer in the 21st Century

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Abstract: In light of the current world economic and environmental crisis due in part to unsustainable development and poor financial planning, 21st Century engineers are faced with unprecedented challenges of developing a sustainable world in balance with the forces of nature to combat global environmental, social and economic crises. The European Union, the United States of America and a number of other countries have identified that smart solutions and highly skilled professionals are needed to survive climate change and create long-term prosperity. In this paper the evolution of the changing career of the engineer will be presented. The policy background to the current system of engineering education at bachelor's and graduate level in Ireland will be introduced and perceptions of engineering as a profession by society in general, and by school leavers selecting third level courses will be discussed. The role of the engineer as a specialist, expert or generalist will also be studied in terms of the changing demands and needs of society. Finally the responsibility of universities, through broad-based multidisciplinary teaching and training, to prepare the next crop of engineers will be examined.

Keywords; Chartered engineer, Industry, Multidisciplinary, Professional engineer, Sustainable development.

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1. INTRODUCTION & POLICY BACKGROUND

The development of the modern world has been dominated by science, engineering and technology and the role of the engineer is linked closely to the needs of society. Unfortunately engineers are either public relations shy or poor communicators of their success. As famous scientists tend to develop medicines, they appear to be viewed by society in a more philanthropic light. The term engineer used in this paper includes any professional scientist, technologist or engineer who uses her skill sets and training to develop practical real world applications. Engineering is not a stationary profession; it is continuingly evolving to include new sub-disciplines. The 21st century will be defined by some of the huge challenges now facing humanity. Among these are energy and food security, competition and scarcity of natural resources, and climate change. This year's engineering graduates will face these issues throughout their working careers. The demand for engineering skills is likely to be higher than ever before in order to deliver sustainable engineering systems, low-carbon energy technologies, and robust physical infrastructure to protect against geophysical hazards such as sea-level rise and extreme meteorological events.

At a local level, Ireland faces all of the above issues to some extent, as well as the pressing additional short-term challenge of dealing with a severe financial crisis, and reducing unemployment in particular. Government policy aims to support long-term economic recovery through the creation of a "smart economy" [1]. This vision for a smart economy will feature increased levels of investment in research and development by indigenous companies and by multinational companies. Additionally, the provision of high quality infrastructure and growth in renewable energy and so-called "green collar" jobs will support this endeavour. The US federal stimulus programme places a similar emphasis on job creation in what has been termed the "green tech" sector. Government policy on education is aligned with the goals presented in the Smart Economy vision. A national strategy for science, technology and innovation has the stated goal of doubling the output of PhD graduates between 2004 and 2013 [2]. Figures compiled by the US National Science foundation in 2004 [3] showed that Ireland's per capita output of PhD graduates was well below that of countries such as Finland, Switzerland and the UK. However, Ireland's PhD output in Science and Engineering disciplines was somewhat better, and is likely to have improved significantly improved since the NSF data were collated. The authors of the government strategy hope that increasing PhD output (and the associated increase in the numbers of postdoctoral researchers and principal investigators) will drive innovation through industrial R&D and the transfer of skills into the enterprise sector, thus reducing the country's reliance on foreign direct investment (FDI) as a source of jobs and tax income to support public services. The mobility of FDI, which constantly seeks lower-cost operating centres, has been to Ireland's advantage, and latterly, disadvantage, which means that it is an unreliable revenue generator for the future.

2. INTRODUCTION & POLICY BACKGROUND

The main focus of the scientist is to develop knowledge and understanding of the physical universe [4]. Science is the pursuit of knowledge in its purest sense without any concern to the needs (or interpreted needs) of society, whereas engineering is the combination of both. A simple Venn diagram in Figure 1 shows the interaction of engineering, science and society adapted from Reference [5].

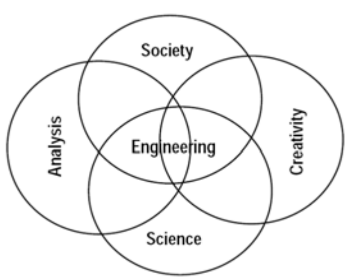

Figure 1 Engineer in Society

Engineering connects pure science to society. Unlike science, in engineering the environment in which engineers plan, design, build, manufacture, maintain and operate continually changes and so the engineer must be prepared within an 'acceptable level of risk' for all possibilities and outcomes. In a controlled laboratory there is much less chance of an uncertain event. The biggest risk factors in engineering are planning for the unknown behaviour of humans and natural systems. In an article entitled 'Engineers, Terrorism and Creationism' published in the New Scientist in 2009 some interesting claims were made about engineers [6]. The article was widely quoted and discussed at the time, and was based on the findings contained in a Department of Sociology, University of Oxford working paper produced by Diego Gambetta and Steffen Hertog [7]. In one simple article more damage was done to the reputation of engineers than centuries of bridge building and service to society. The study carried out by Gambetta and Hertog concentrated on a particular religious group in a specific geographical area and obviously the data were skewed from the start. Engineers have contributed very largely to society, but are a misunderstood group, as their efforts are often under-appreciated. Delivery of most of the services essential to modern life such as electricity, flight, television, medical imaging, sewage networks, the telephone, water networks and railway lines are the result of engineering. Engineers plan, design and create the physical structure through which society lives, works and plays. Therefore in order to appreciate and understand the role of the engineer in the 21st century we must examine the relationship between the engineer and society. Then, perhaps 21st Century engineers can develop a sustainable world in balance with the forces of nature to combat some of the inventible global crisis if given the opportunity. In this paper the evolution of the changing career of the engineer is presented. The role of the engineer as a specialist, expert or generalist will also be studied in terms of the changing demands and needs of society. Finally the responsibility of universities through multidisciplinary teaching and training to prepare the next crop of engineers will be examined. This study is based on some freely available statistics and figures from Ireland.

3. Engineering Educations in Ireland

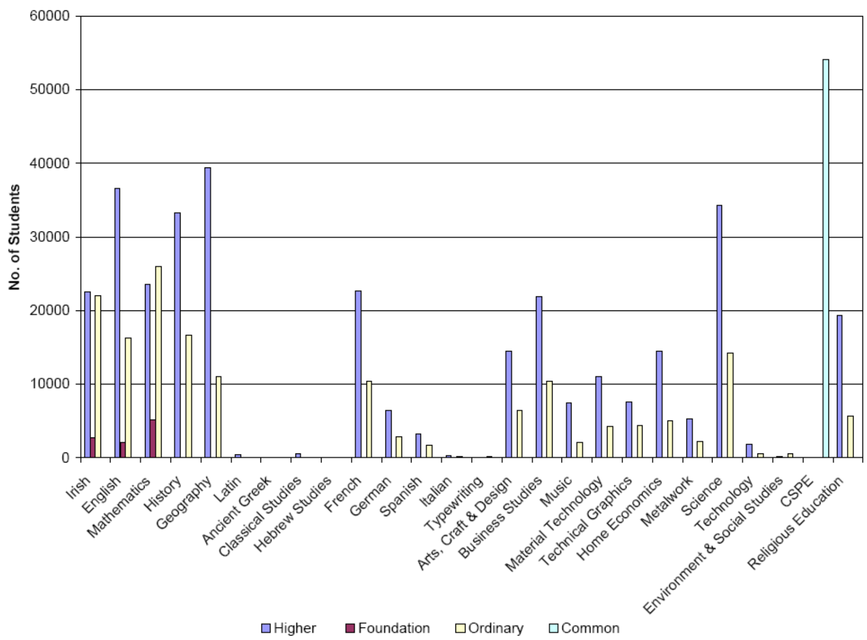

Figure 2 No. of Students per Subject Junior Certificate 2009

The Irish secondary school system (ages 12-18 approximately) is divided into two cycles, a three or four-year Junior cycle followed by a two or three-year Senior cycle. The cycles culminate in the state-run Junior and Leaving Certificate examinations. Figure 2 shows a breakdown of the 2009 number of students per subject at the Junior Certificate level [8]. There are 34 subjects taught at Leaving Certificate level with an additional number of European Union language subjects available upon request. In 2009 there were 49 subjects taken. Entry to University or third-level colleges is determined by a point score, derived from grades awarded in the Leaving Certificate examinations. The core Junior Certificate subjects change at the Leaving Certificate level to Biology, Geography and Business along with English, Irish and Mathematics. So how do subjects, such as honours Mathematics, History and Science, so popular and successful at Junior

Certificate level, fail to attract interest at the Leaving Certificate level? Anecdotal evidence from the authors' own school days (20 years ago) that history, mathematics and physics and chemistry are perceived as tough, long courses where it is difficult to achieve a high grade. The statistics seem to indicate that the situation has not improved.

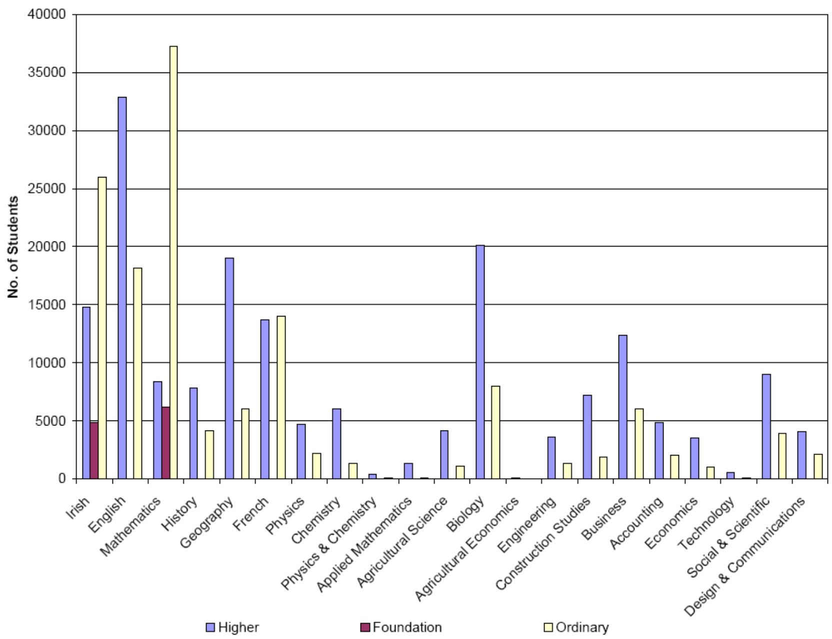

Figure 3 No. of Students per Subject Leaving Certificate 2009

A review of the course syllabi, content and examination papers of the years up to 2009 supports this statement. Students are becoming cannier, the examination papers are more predictable and in the era of Celtic Tiger students learned that the total number of points (irrespective of the subjects) is the measure of academic success. Nowadays, full marking schemes are made available after the examination, together with model answers. A student like everybody else in life would take the path of least resistance and in this instant the statistics prove with the tapering off of history, chemistry, physics and mathematics suggests that this is the path less travelled. Geography and biology maintain their popularity from junior to senior cycles. Figure 3 shows the breakdown of subjects taken at Leaving Certificate level in 2009. The difference between the core subjects at honours and ordinary level from Junior Certificate is interesting.

What does this indicate? The student is making a practical decision to maximise their lifelong opportunities by avoiding the subjects with the most constraints. To the uninitiated it indicates that these subjects with the same amount of effort produce a better chance of success. If we carry this mind-set through then it is easy to postulate that second level students examine the choices available at third level and again make their choice on the path of least resistance. Obviously potential earnings, career advancement and job security play an important role in their ultimate choice, but unfortunately these are rarely guaranteed in engineering. Second level students struggle when asked to name a famous engineer, whereas Marie Curie, Louis Pasteur and Albert Einstein are readily named as examples of famous scientists.

Every year there is media attention given to the 'problem' that we do not produce enough engineers. This could be attributed to the honours Mathematics entry requirements into some engineering courses. In science the number of enrolments holds fairly steady year on year [9]. The question is, do we really need any more scientists and engineers than we already produce? More PhD degrees are awarded in the sciences than in any other field in the world annually [10]. In engineering a PhD is not an industrial norm in R&D, whereas it seems to be a prerequisite in many fields of science. Some argue that the education is an indicator of economic success of a country and figures from the Organisation for Economic Co-operation and Development (OECD) seem to support this assertion [10]. However, to what stage of education and to what degree of financial support? The following are some statements from the same OECD report:

- *'Investment in research and development (R&D) for the environment in so-called clean technologies such as renewable energy (+20%) to air pollution control (+12%) to mitigate climate change effects increased substantially from 1996 to 2006 (OECD, 2009).*
- *Scientific studies are more popular in Korea and the Nordic countries, where science and engineering (S&E) degrees account for 37% and 29%, respectively, of total awards. In most OECD countries, universities deliver more engineering than science degrees.*
- *OECD governments are concerned about the low level of female participation in scientific studies. The presence of women is overwhelming in humanities and the arts (67%), health (74%) and education (75%) but low in engineering (23%) or computing (23%). 40% of OECD doctoral students graduate in scientific fields; the S&E orientation of doctoral programmes is even more pronounced in emerging countries.*
- *In many OECD countries doctoral degrees have multiplied faster than other university degrees. Despite their greater propensity to graduate at tertiary level, women represent on average 46% of tertiary-level employment. Earnings differentials between males and females still remain significant in all OECD countries.*
- *Foreign affiliates provide access to new markets and new technologies for domestic firms. In 2006, the share of firms under foreign control in total turnover in manufacturing varied from about 80% in Ireland to 3% in Japan.*
- *The share of foreign affiliates in industrial R&D varies widely across countries, ranging from 5% in Japan to over 60% in Ireland and the Slovak Republic.*
- *Doctorate holders have a research qualification and are a pillar of the research system. Their presence is an indicator of a country's attractiveness for new and foreign talents. Employment of doctorate holders ranges from 97% to 99% and exceeds that of university graduates (83% to 89%).*
- *Many doctorate holders face temporary employment in the early stage of their careers. After five years of activity, 60% of doctorate holders in the Slovak Republic and over 45% in Belgium, Germany and Spain remain under temporary contracts. Yet permanent engagements account for over 80% of all jobs in almost all countries.*
- *The earnings premium from education is an important incentive for individuals to enrol in tertiary education. In all OECD countries, annual earnings increase with educational attainment levels. In the Czech Republic, Hungary, Portugal and the United States, the average earnings premium for a tertiary-level diploma holder was no less than 75% in 2006. Such differentials are traditionally smaller in Nordic countries and lower than 30%. Over the past decade, the earnings premium of highly skilled workers decreased the most in Italy (–6.4%), Ireland (–4.3%), Hungary (–4%), Germany (–3.4%) and Poland (–2.9%). The opposite trend is observed in Australia, New Zealand, Spain and Sweden it increased at an average annual rate of between 1% and 3%.*

In Ireland generally one third of all PhD students are enrolled in the Science disciplines and headcounts indicate that a third go on to academia, a third go onto to private sector R&D and the remainder find some other type of employment [9]. This does not include Engineering. Figure 4 shows actual PhD graduation statistics from 1999 to 2008, for all disciplines and by gender.

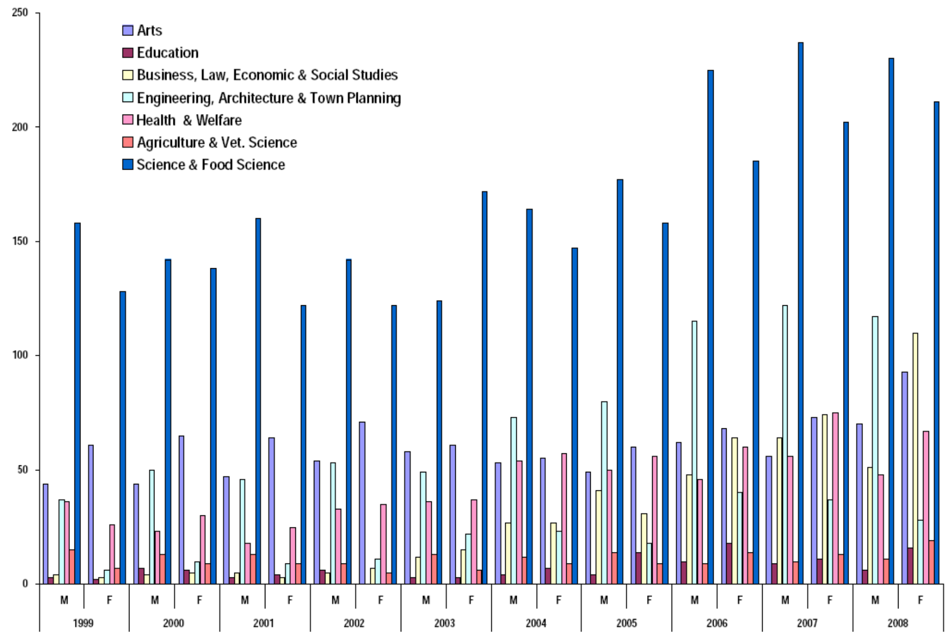

Figure 4 PhD graduation statistics from 1999 to 2008 [9]

The National Development Plan (NDP) 2007 – 2013 put higher education at the heart of national policy and the following were identified as needs to be addressed over the lifecycle of the plan [11]:

- *'Increased participation and improved access;*
- *Encourage a greater flexibility of course offerings to meet diverse student population needs in a lifelong learning context;*
- *Promote the quality of teaching and learning;*
- *Significantly increase PhD numbers and research activity;*
- *Effective technology transfer; and*
- *Safeguard and reinforce the many roles of higher education in providing independent intellectual insights and in contributing to our broader social, human and cultural understanding.'*

Are third level institutions producing the calibre of graduate engineer really up to the demands of industry? Anecdotal evidence in Ireland over the last number of years seemed to indicate that there was some unease with the grades awarded to students and their actual ability in the private sector. Nearly a third of every graduating engineering class had a first, compared to perhaps only 3% twenty years earlier. Yet, these graduates seemed to lack the simple fundamentals of engineering and professional etiquette. Recently this garnished some media attention [12]. There are reports, which seem to indicate that there is some grade inflation (to varying degrees) since 1996 [13 and 14]. A report in the United Kingdom produced when there was similar rumours, concluded that students must be working harder [15]! This is not a new phenomenon and internationally these concerns are raised and discussed regularly. The question should be asked of engineering and science, does it require a certain level of numerical ability and if we loose our minimum entry requirements are we really producing the right calibre of graduate for industry?

During the late 20th century a trend towards greater specialisation was apparent, with bachelor's degrees being offered in specialised niche areas such as biomedical engineering, optoelectronics, mechatronics, building services engineering etc. This was particularly the case in the UK but also occurred in Ireland. There are currently 78 honours engineering degree programmes offered in the Republic of Ireland [16]. Of these, 21 could be said to be in niche areas including biomedical engineering, transport technology, sports and exercise engineering and multimedia systems. Only 8 of the courses are described as general (undenominated) engineering upon entry. Engineers and scientists have created incredible technology using their minds, logic and cognitive abilities for the betterment (in most part) of society. It is time for us to upgrade and sharpen our scientific minds to integrate diverse perspectives. The new globalisation paradigm requires adopting new tools to turn our altruistic nature into a positive force to take control of the policies, which shape our world. Engineers and scientists know how to make this world sustainable and support us all, but can society accept this? Perhaps the profession of engineers needs to embrace a student with better sales skills and lower mathematical and analytical skills? Otherwise will our accumulated knowledge continue to be limited to the 10 minute power point briefing session presentation? How do we encourage such students into our ranks, if from they are lost when they make their subject choices for the Leaving Certificate? Can an engineer's communications skills really be improved? Better career opportunities, which of course include salary and management opportunities, may encourage students with the same scientific ability into engineering.

Albert Einstein is quoted for saying many things, but perhaps one of his less cited quotes is '*Science is a wonderful thing if one does not have to earn one's living at it*'. The same could also be said about engineering. Engineers and scientists tend to earn far less than other professions with comparable educational requirements. The famous cartoon character Dilbert's 'Salary Theorem' states that '*Scientists and Engineers can never earn as much as administrators and sales people*.' Aside from the salary an engineer or scientist who pursues such a career knows from the onset that the career opportunities aren't that great, but they do perceive challenges and continually training and knowledge advancement, sadly this is not always the case. This raises the issue of the specialist versus the generalist. In engineering if an employee is pigeonholed as an expert in a specific area, such as traffic, circuit design, programming, concrete design, computer aided design (CAD), or report writing, it can paradoxically become career-limiting, as the scope for career advancement opportunities reduces. Every engineer finds this limiting and it goes against their very nature. There are numerous engineers, particularly in local authorities where the opportunity to change area or focus is very rarely available. This does not give the tax payer value for money. At the end of the day the purpose of the engineer whether in the private sector, public sector, semi-state or academic world is to be productive, sometimes the productivity can be very slow due to the nature of the environment. In this new 21st Century era of limited resources engineers must be smarter and climb the hurdles of mediocrity placed in our way to guarantee a better society for all.

4. Discussion & Conclusion

The challenges of sustainability and responding to climate change, outlined in the introduction, will define the careers of 21st century engineers. It is likely that engineers will have to work across the traditional boundaries of sub-disciplines such as electrical, mechanical, civil and process engineering in order to meet these challenges. The authors believe that this will necessitate a shift in how engineering is taught in third-level education, reversing the trend of recent decades towards increasing specialisation at undergraduate level, as generalists will be more likely to be able to tackle the cross-disciplinary aspects of the challenges of the 21st century. In this respect, a shift towards multi-disciplinary thinking, where engineers with a broad-based education can quickly adapt to different areas, rather than inter-'disciplinarity', where multiple specialists remain within their own disciplines but attempt to collaborate to solve problems, is more likely to succeed. Therefore the authors envisage a return to the more broad-based engineering degree programmes which were prevalent in the mid-20th century, with a solid emphasis on mathematics, mechanics and physics in the early years before specialisation is encouraged. This paper has examined at a high level the role and development of the engineer in society in the 21st century. It has identified and discussed areas of concern to the engineer, including the calibre of graduate, career advancement and opportunity and grade inflation and the measurement of success in academia. Engineers have much to offer society, but this can only be done if engineers actually participate in society. The current portfolio of engineering courses offered by third level institutes will have to change in order to equip this generation of engineers to deal with the challenges of the 21st century.

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