Chapter 16
Transforming Engineering Education: For Technological Innovation and Social Development

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Abstract Engineering, and engineering education, drive innovation, social, cultural and economic development, and are vital in addressing global challenges such as sustainability, climate change and poverty and the other UN Millennium Development Goals.

This chapter examines the urgent need for innovation and transformation amid changing modes of knowledge production, dissemination and application, and to counter declining interest, enrolment and retention in engineering education, the shortage of engineers reported in many countries, brain drain of engineers from developing countries and consequent impact on development. Student-centred, project- and problem-based learning (PBL) plays an important role in this process, together with an emphasis on humanitarian engineering and technology – combining fun and fundamentals, and the need for engineering to be seen as a major factor in development and addressing global issues and challenges. The chapter emphasises the need to develop engineering studies, policy and planning to support and facilitate this process.

Keywords Engineering • Education • Innovation • Transformation • Development • Problem-based learning • Poverty reduction • Sustainable development • Climate change

Introduction

Engineering knowledge and application drives innovation, social and economic development around the world. Our physical infrastructure is designed, built and maintained by engineers, and most innovations derive from engineering (Metcalfe

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2009, also 1995). Significant change in knowledge production, dissemination and application has taken place over the last 50 years, driven by and generating associated needs for engineering. Engineering is the most radical profession, in terms of technological, social, economic and cultural change. On the other hand, engineering is conservative, and engineering education has changed very little over this period. This is a factor in the decline of interest, enrolment and retention of young people in engineering, reported shortages of engineers in many countries and brain drain from developing countries.

This is a major challenge for engineering, and occurs at time of two other major global challenges – the need to mitigate and adapt to the effects of climate change and facilitate the sustainable use of resources, and the need to reduce poverty and enhancing the quality of life for the 20 % of humanity who live in poverty, on less than 1$ per day (1.3 billion people, 70 % of them women). Engineering and engineering education are of vital importance in addressing climate change and in improving housing, water supply, sanitation, food, nutrition, transport, communications and employment creation, through the development and application of humanitarian engineering.

Historical Background of Engineering and Engineering Education

Enlightenment thinking was instrumental to and continued into the Industrial Revolution – powered by engineering knowledge, application and education, which developed rapidly in eighteenth century England, transferring to Europe, North America and world. Machines replaced muscle in manufacturing, in a synergistic combination of knowledge and capital. The first Industrial Revolution took place from 1750 to 1850, focused on the textile and related industry. This was the first of the 'Kondratiev waves' of innovation, industrial development and surges in the world economy – periods of alternating sectoral growth, initially of around 50 years duration but decreasing with increasingly rapid knowledge change. Five major waves of innovation have been identified as part of the 'Schumpeter-Freeman-Perez' model. The second wave or revolution focused on steam and the railways from 1850 to 1900. The third wave was based on steel, electricity and heavy engineering from 1875 to 1925. The fourth wave was based on oil, the automobile and mass production, from 1900 to 1950 and onward. The fifth wave was based on information and telecommunications and the post-war boom from 1950. The sixth wave, based on new knowledge production and application in such fields as IT, biotechnology and materials, began around 1980.

This model is generally accepted, although the precise dates, phases, causes and effects of these major changes are subject to debate. A seventh wave would appear to focus on sustainable 'green' engineering and technology, and began, at least conceptually, at the time of the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992, with interest increasing from 2005. Green technology was emphasised at the Rio+20 conference in 2012, although engineering has been overlooked, undervalued and marginalised. It is important to note the six major waves of technological innovation have all been reflected in subsequent innovations and transformations in engineering education (Beanland and Hadgraft 2013). It is therefore timely to be considering transformations based on new knowledge production, application and sustainability.

Development of Engineering Education

The eighteenth and nineteenth centuries were a crucial period in the development of engineering – particularly the Iron and Steam Ages, the second wave of innovation and industrial revolution. Early interest in the development of engineering education began in 1702 in the German mining industry, with the creation of a school of mining and metallurgy in Freiberg. The Czech Technical University in Prague was one of the oldest technical universities, founded in 1707. Engineering education in France developed with the creation of the École Nationale des Ponts et Chaussées (established in 1747) and École des Mines (1783). The École Polytechnique was established in 1794, during the French Revolution, to teach mathematics and science – the revolution in engineering education beginning during a revolution. France developed a formal system of engineering education after the Revolution, under Napoleon's influence, and engineering education has retained a strong theoretical and military character in France. At the beginning of the nineteenth century, the French model influenced the development of polytechnic engineering education institutions around the world, especially in Germany. Between 1799 and 1831 polytechnics were established in Berlin (1810, by Wilhelm von Humboldt, establishing the university model we see today – see below), Karlsruhe, Munich, Dresden, Stuttgart, Hanover and Darmstadt. In Germany, polytechnic schools were accorded the same legal foundations as universities. In Russia, schools of technology were opened in Moscow (1825) and St. Petersburg (1831), based on the model of military engineering education. The first technical institutes appeared at the same time in the USA – including West Point in 1819 (modelled on the École Polytechnique), the Rensselaer School in 1823 and Ohio Mechanics Institute in 1828.

In England, on the other hand, after the early years of the Industrial Revolution, engineering education continued to be based on the model of apprenticeship with a working engineer, and many engineers had little formal or theoretical training. Famous men such as Arkwright, Hargreaves, Crompton and Newcomen, followed by Telford, Maudslay, George and Robert Stephenson, all had little formal engineering education, yet developed technologies that powered the Industrial Revolution and changed the world. Practical activity preceded scientific understanding in many fields, – steam engines preceded thermodynamics, for example, and 'rocket science' is more about engineering than science. England tried to maintain technological lead by prohibiting the export of engineering goods and services in the early 1800s. This was one reason why countries in continental Europe developed their own engineering education systems based on French and German models, with a foundation in science and mathematics, rather than the British model, based on artisanal empiricism and laissez-faire professional development. Through the nineteenth and into the twentieth centuries, however, engineering changed and with it engineering education. England was also obliged to change toward a science and university-based system, partly due to fears of lagging behind the European model in terms of international competitiveness. This reflected the rise of the 'engineering sciences' and increasingly close connection between engineering, science and mathematics.

Toward the end of the nineteenth century, most of the industrialising countries had established their engineering education systems. These were based on the liberal, student-centred model introduced by Wilhelm von Humboldt at the University of Berlin, combining theory and practice, with a focus on scientific research. The German "Humboldt model" went on to influence the development of universities in France and elsewhere, although the emphasis on practice as well as theory was often later overlooked. Over time, emphasis on the practical gave way, largely on professional grounds and the desire to emulate science, with an increasing focus on theory. This has now had a negative impact on the interest and enrolment of young people in engineering, and consequent need for educational approaches for the next generation of engineers based on problem-based learning, projects and real-world needs.

In the twentieth century, the professionalization of engineering continued with the development of learned societies and the accreditation of engineers through qualification and continued professional development. Universities and professional societies facilitated education, research and the flow of information through journals, technical meetings and conferences. This activity continues with the development of international accords, standards and accreditation for engineering education, and the mutual recognition of engineering qualifications and professional competencies. These include the Washington Accord (established in 1989), Sydney Accord (2001), Dublin Accord (2002), APEC Engineer (1999), Engineers Mobility Forum (2001) and the Engineering Technologist Mobility Forum (2003), and, in Europe, the Bologna Declaration in 1999 relating to quality assurance and accreditation of bachelor and master programmes.

Changes in Knowledge Production, Dissemination, Application and Innovation

It is important to note that the waves of technological innovation and industrial revolution reflected in transformation in engineering education, were also reflected epistemologically in changing knowledge production, dissemination and application. The first major wave of technological change in the early 1800s, based on iron and water power, was reflected in a craft mentor-based hands-on approach. The second wave in the later 1800s, based on steam, was reflected in apprenticeships and trades. The third wave in the later 1800s and early 1900s, based on steel, was reflected in the development of technical schools, colleges and universities. The fourth wave in the early/mid 1900s, based on oil, reflected an increasing science, theory and hands-off approach. The fifth wave, post 1950s, based on ICTs, reflects the significant changes in knowledge and technology over the previous 50 years, as does the sixth wave, based on changes in knowledge production, dissemination and application from the 1980s – with "post-industrial science" and the convergence of science and engineering based on interdisciplinarity, networking and a problem-solving, systems approach, with an increasing focus on applications. These changes relate particularly to what has been typified as the change in knowledge production from "Mode 1" (academic/disciplinary) toward "Mode 2" (problem-based/interdisciplinary) (Gibbons et al. 1994 and Nowotny et al. 2001; Etzkowitz and Leydesdorff 2000). Changes from theory toward practice, individual to teamwork, with converging bodies of knowledge, professional practice and employment, need to be reflected by change in science and engineering education toward project- and problem-based, student-centred learning. These changes will be needed in the move into a seventh wave, based on cleaner/greener technology for climate change mitigation and adaptation, where a focus on practice, teamwork, converging knowledge, applications and innovation will be of paramount importance.

Innovation

Innovation and waves of innovation are the history of the world. The Stone Age did not give way to the Bronze Age because they ran out of stones (Yamani 1973). Innovation relates to the introduction, dissemination and use of an idea, method, product or process that is new to the user or user group, but may not be absolutely new. Innovation initially related particularly to technological innovation, although the meaning has now expanded to include broader subjects – such as innovation in education. Epistemologically, innovation was first portrayed as a linear model, where basic science was imagined to lead to applied science, engineering, technology, innovation and dissemination of ideas, products and processes. The linear model of innovation, initially promoted by Vannevar Bush, proved to be deceptively simple and endearing, especially for the science community and policy makers in the post-war period. Although the model has later been shown to be inaccurate and misleading, its simplicity and usefulness for science in the argument for funding in the public policy debate has proved enduring. Academic policy analysis has moved forward, toward systems thinking, "national systems of innovation" and related regional and global models (Freeman 1995; Lundvall 1992). Most recently, the "ecosystem" model of science, engineering, technology and innovation has appeared, as a metaphorical didactic finesse, but offers little in terms of epistemological insight, and may confuse the casual observer. While the systems models may be more accurate for economically developed, OECD member countries (where they were developed, with particular reference to Japan), they can also be misleading in the developing, non-OECD country context, where elements of the innovation system (industry, research, government) are less developed.

In the context of innovation in education, it has been noted that educational practices change slowly and evolve to match cognitive and professional paradigms, requirements and expectations. In engineering education, "engineering science", following the Humboldt model, is the dominant paradigm. Changes in knowledge and technology production, dissemination and application have occasioned the need for change in associated learning approaches – toward cognitive, knowledge- and problem-based learning, and the need for innovation and development in engineering education. Engineering is a problem-based profession, and needs a problem-based, just-in-time approach to learning and continued professional development (UNESCO 2010). It is not easy to identify emerging needs in terms of changing knowledge production, dissemination and application, cognitive and professional paradigms. In the case of engineering, we are fortunate that the needs for the next generation of engineers are reflected in the twelve graduate attributes and professional competencies as identified in the Washington Accord (Washington Accord):

1. Engineering knowledge
2. Problem analysis
3. Design/development of solutions
4. Investigation
5. Modern tool usage
6. The engineer and society
7. Environment & society
8. Ethics
9. Individual & team member
10. Communications
11. Project management & finance
12. Life-long learning

As can be seen, only five or six of these criteria relate to the "core" or "old" engineering curricula, with the other half relating to more modern needs in terms of professional practice (interestingly, along the lines originally advocated by von Humboldt, before practice gave way to theory).

Issues and Challenges Facing the World, and Engineering

The main overall challenges facing the world relate to the Goals of the Millennium Summit (the Millennium Development Goals – MDGs, 2000–2015), and the post-2015 Development Agenda, presently under discussion in the UN (with a spotlight on the role of science, technology and innovation, without overview mention of engineering). The MDGs include, particularly, poverty reduction – enhancing the quality of life for people living in poverty, and sustainability – promoting environmental sustainable development, climate change mitigation and adaptation. These are also the main global issues facing engineering, and engineering is vital in addressing these goals. Engineering also has its own internal issues and challenges, especially the shortages of engineers reported in many countries, and associated decline of interest and enrolment of young people in engineering – which is a major concern for future capacity and addressing international development goals.

The 2000–2015 UN Millennium Development Goals, consist of 8 overall goals, with 18 quantifiable targets measured by 48 indicators. The overall goals are:

1. Eradication of extreme poverty and hunger
2. Achievement of universal primary education
3. Promotion of gender equality and empower women
4. Reduction of child mortality
5. Improvement of maternal health
6. Combating HIV/AIDS, malaria and other diseases
7. Ensuring environmental sustainability
8. Development of global partnership for development

These goals are aspirational and qualitative rather than actual, although the targets and indicators are more quantitative. As may be the case with such goals, success has been limited by the difference between aspiration and reality, and only three of the eighteen quantifiable targets have so far been achieved, boosted by economic development in China and India, but constrained by the Global Financial Crisis. As is also the case with such visionary and aspirational goals, there was little mention of how they might be achieved, or what areas of knowledge might be important or instrumental in achieving them. The role of science and technology was only mentioned in relation to MDG8, target 18 relating to ICTs (the very last target), for example, and there was no mention of engineering. Limited success in achieving aspirational MDGs in a time of economic crisis may be of little surprise, given the scope of the challenge, and emphasizes the need for more realistic, measurable goals and appropriate indicators. It also emphasizes the need for better delineation of how such goals may be achieved, the vital role of engineering and technology in the process, and the generally outdated understanding of the role of engineering and technology in development by the "aid" community and associated policy makers and decision takers.

Issues and challenges facing the world are listed below, in terms of the percentage and numbers of the world population that do not have access to the areas of basic need noted above.

39 %	2.6 billion people	Do not have safe water
35 %	2.3 billion people	Do not have improved sanitation
24 %	1.6 billion people	Do not have electricity
20 %	1.3 billion people	Live in poverty (<1$/day, 70 % women)
15 %	Over 1.0 billion people	Lack adequate housing/live in slums
15 %	Over 1.0 billion people	Lack any ICT connection
13 %	852 million people	Go hungry every day

Life expectancy – poor countries: 52 years; rich countries: 78 years

Addressing basic needs in these areas is an engineering issue, with engineering solutions. Engineering is essential in this process, and engineering education, in developing and developed countries, needs to focus on the development of curricula and learning approaches to graduate engineers with the attributes and competencies to address these challenges. Student-centred, project- and problem-based learning will be vital to address such real and relevant world issues and challenges.

Poverty Reduction and Engineering

Poverty is a major issue and challenge facing the world. Poverty is defined conventionally as living below US$2 per day, and extreme poverty as living below $1.25 per day. Poverty therefore relates particularly to the developing and least developed countries, although not exclusively so – there are examples of relative poverty in most cities and countries around the world. In 2012 the World Bank released data from a study over the period 2005–2008 indicating that, while absolute numbers had increased, the percentage of people living in poverty had declined for the first time since 1981, estimating in 2008 that 2.49 billion people lived on less than $US2 a day and 1.29 billion below US$1.25, down from 2.59 and 1.94 billions in 1981, respectively. The eradication of poverty, especially extreme poverty, is the first of the UN Millennium Development Goals. Poverty depends on social and economic context and such issues as access to land and resources, and is a measure of income and resource distribution and inequality. Poverty is also gendered – 60 % of the world's poor are women, who are also in many countries mainly responsible for family care and services.

Although conventionally considered, measured and indicated financially, poverty relates essentially to the access of people to the resources with which to address basic human needs. This depends on resource availability and population pressure – people living in poverty spend more of their income on basic needs such as food, and are especially vulnerable to increases in the cost of living. Poverty depends on natural factors such as drought and famine, and also on government policies regarding income and resource distribution. In the 1980s, for example, free market policies of economic liberalization and structural adjustment cut government support of social programs, subsidies and public financing in developing countries and lead to an increase in poverty and a substantial increase in inequality within and between countries. In the context of access to resources, poverty is also defined as a denial of basic human rights to food, housing, clothing, a safe environment, health and social services, education and training, decent work and the benefits of science and technology.

While poverty is often thought of economically, it relates primarily to the limited access of people living in poverty to the knowledge and resources with which to address their basic human needs and promote sustainable economic, social and human development. Areas of basic human need include water supply, sanitation, food production and processing, housing, energy, transportation, communication, income generation and employment creation. Addressing basic needs in these areas consists essentially of the transfer, innovation and application of engineering and technology appropriate to the social, economic, educational and knowledge situations in which poor people live. Such engineering and technology has to be appropriate to context – to be affordable, understandable and build upon local knowledge, skills and materials. This requires an understanding of the needs and knowledge systems of people living in poverty and their participation in the identification, development, adaptation, transfer and application of appropriate engineering knowledge and skills and technology. The development of agricultural technologies in the Industrial Revolution revolutionized rural and urban productivity in line with increasing populations, and dramatically reduced poverty. This helped to break the perception that food shortages and poverty were an inevitable fact of life.

Engineering and technology consists of ‘hardware’ tools, equipment and infrastructure, and ‘software’ knowledge that develops the technology that surrounds and supports people around the world. The application of engineering and technology helps address poverty at all levels. At the macro level, neo-classical and later economic growth theories paid increasing reference to technology and innovation as the main drivers of economic development and growth, and emphasise economic growth as the main factor in the reduction of poverty, despite criticism of the ‘trickle down’ effect. Recent research also indicates that growth does not necessarily reduce poverty, but also requires government policies that reduce inequality, with infrastructure playing a key role. At the middle level, many businesses in developed and developing countries are medium and small-scale enterprises, employing less than 250 or 50 employees, and many more businesses are at the micro level with less than 10 employees. Around the world, especially in developing and least developed countries, micro, small and medium scale enterprises (MSMEs) represent the vast majority of companies and jobs, up to 50 % of GDP, and higher growth compared to larger industries. Many MSMEs are focused on particular technologies and innovations.

Engineering and technology is most vital and visible in addressing basic human needs and improving the quality of life of ordinary people in direct applications at the community and family level – in both villages in rural areas and in urban communities. Engineering and technology is vital for the provision and development of water and food supply and other areas of basic need. Examples include domestic food processing tools, the construction of wells, water tanks and improved toilets, equipment and techniques, animal- and engine-powered farm machines, better housing and cooking stoves, low-cost roads and mobile phones. Enterprise and technology helps create income and jobs, but technology for the poor does not have to be poor technology, or low technology. One of the greatest challenges for the next generation of engineers will be to continue to address poverty. Engineering and technology needs to be appropriate to the social, economic, educational and knowledge situations of people living in poverty in order to facilitate and enable them to address their own basic needs, alleviate poverty and promote sustainable livelihoods and development. This requires effective policy formulation, implementation, and the integration of engineering and technology into such debt relief and aid qualifiers as Poverty Reduction Strategy Papers (PRSPs). It also requires effective capacity and capacity building, and the education and training of young engineers, particularly those in developing countries, to be aware and sensitive to the role of engineering and technology in poverty reduction. Government ministries and departments, donor agencies, universities, NGOs and other relevant organizations need to be encouraged and supported in this process with the transfer of information and experience.

The identification, development, adaptation, transfer and application of engineering and technology also requires the provision of information, learning and teaching material using multimedia approaches and ICTs for human and institutional capacity building, and associated support services, particularly micro-finance, to promote technological innovation and application. Technology can then empower the poor by helping them to address their basic needs to reduce poverty – this is a human right and this approach should therefore be central to a rights-based approach to poverty eradication. Specific regional and social dimensions of poverty and poverty eradication require reference to particular areas and issues – including urban and rural poverty, the problems of young people, the elderly, women and gender issues and the 'feminisation' of poverty. The poverty divide is therefore closely connected to the knowledge and technology divide, and the world can be seen to be divided into technology innovators, technology adopters, and the technologically excluded (Sachs 2000). The number of scientific research papers and patents per capita population, for example, is in absolute reverse correlation to measures of poverty. It is the responsibility of engineering and engineering educators to address and reduce the knowledge and technology divides.

Sustainable Development, Climate Change, Engineering Capacity and Education

There is an increasing global challenge regarding the need for development to be environmentally sustainable and for mitigation and adaptation to climate change, especially sea level rise. The use of resources needs to be sustainable for future generations, and better protection from pollution and degradation will be needed. The use of natural resources has approached and in some cases exceeded critical limits, natural and man-made disasters are more frequent, and the economic gap and "knowledge divide" between the rich and many poor countries continues to widen. These issues are a major threat to global prosperity, security, stability and sustainable development.

Engineering is at the heart of sustainability, and sustainability is a major challenge for engineering. Most countries now recognize the need for sustainability and agree that there is an urgent need to reduce emissions and use resources more efficiently, if we are to mitigate and minimize the catastrophic effects of climate change. The question is how to achieve this, amid increasing population pressure and consumption? This question was first raised in 1972, with the publication of "Limits to Growth" by the Club of Rome, and created major interest, concern and debate, which has unfortunately declined since that time. Many countries recognized the need for policy instruments and initiatives to mitigate climate change prior to the 2009 United Nations Climate Change Conference in Copenhagen, and similarly for sustainability prior to the UN Conference on Sustainable Development in 2012. Unfortunately, both COP15 and Rio + 20 failed to deliver any binding agreements and were broadly disappointing, especially for the science and engineering communities – with engineering hardly mentioned at Rio + 20 and in associated documents. Addressing these issues, and the specific outcomes and follow-up to COP15 and Rio + 20, will be a challenge for engineering. This includes the development of environmental engineering, the greening of engineering, and the need for the engineering community to ensure that engineering and technology are on the agenda for sustainable development and climate change mitigation and adaptation.

The Intergovernmental Panel on Climate Change (IPCC) has emphasised the importance of technology and finance in climate change mitigation and adaptation. Despite this, the role of engineering in sustainable development is often overlooked. At the same time, there is a declining interest and enrolment of young people, especially young women, in engineering. This will have a serious impact on capacity in engineering, and our ability to address the challenges of sustainable development, poverty reduction and the other MDGs. The most pressing challenge for engineering is to ensure that there are enough appropriately qualified and experienced engineers to meet this demand. This will require the development of new, more interesting and hands-on courses, training materials and systems of accreditation featuring sustainability. Young people will hopefully be attracted to such courses, which will raise overall awareness of the role and importance of engineering in sustainable development, at the centre of building a carbon-freer future.

Significant investment in technology and infrastructure will be required to enhance sustainable development and climate change mitigation and adaptation. The use of coal may double by 2030, and so will the need to develop carbon capture and sequestration and related technologies – this will be a challenge on a technological scale similar to that of the petrochemical industry. Many countries were looking to develop nuclear power generation, which abated in the shadow of Fukushima, although seems to be returning, even though the nuclear industry has declined over the last decades. Renewable energy has developed over the last decade, and will need further development, marketing and incentives. Similar comments apply to other sectors, such as housing and transportation, and many new engineers will be required as the demand for knowledge and technology increases. While market demand attracts young people into engineering, it takes over 5 years to develop courses and graduates, and over 10 years to train and accredit an engineer – so urgent government support will be required for course development and associated R&D and innovation. Although investment in current technology is a pressing issue, R&D for new technology is also urgent, and governments need to invest now to stimulate R&D and industry in the direction of the coming wave of sustainable technological development, which will need to be at the centre of the engineering agenda.

How can the public understanding of engineering and application of engineering in sustainability be promoted? Public understanding and interest in engineering is facilitated by an understanding of engineering as a vital part of the solution to sustainable development, climate change mitigation and adaptation. University courses can be made more interesting with the transformation of curricula and pedagogy and use of less formulaic approaches that turn students off – with more activity, project and problem-based learning, just-in-time approaches and hands-on applications relating to sustainable development. These approaches promote the relevance of engineering, address contemporary concerns and help link engineering with society in the context of sustainability, and need to build upon rather than displace local and indigenous knowledge. These challenges are linked in a possible solution to promote sustainability and enrolment – many young people are concerned about sustainable development, climate change and other international issues such as poverty, and are attracted to engineering when they see engineering as part of the solution, rather part of the problem. Engineering has changed the world, but is professionally conservative and slow to change – there is a need for innovative examples of schools, colleges and universities around the world that have pioneered activity in such areas as problem-based learning. Engineers introduced just-in-time techniques in industry, and need to do the same in education.

Engineering education needs to be transformed to respond to rapid change in knowledge production and application, with the emphasis on a cognitive, problem-solving approach, synthesis, awareness, ethics, social responsibility, experience and practice in national and global contexts. There is a need to learn how to learn, to emphasize the importance of lifelong and distance learning, continuous professional development, adaptability, flexibility, interdisciplinarity and multiple career paths, with particular reference to engineering and sustainability. While the need for holistic and integrated systems approaches in engineering has been recognised, there is still a need to share information on what this means in practice, and to share pedagogical approaches and curricula developed in this context. This is particularly important for universities and colleges in developing countries, with serious constraints of human, financial and institutional resources to develop such curricula and learning/teaching methods. The transformation of engineering and engineering education will be essential if engineering is to catch the seventh wave of technological revolution in innovation for sustainability.

Knowledge development and application in engineering is vital for sustainable social and economic development, climate change mitigation and adaptation. To promote international cooperation and bridging the "knowledge divide", however, engineering needs to be more closely positioned at the centre of the sustainable development and climate change debate and policy agenda. Sustainable development and climate change also need to be positioned at the centre of the engineering agenda. An important contribution in this context and the "Limits to Growth" debate was the publication of Ernst von Weizsäcker's "Factor Four: Doubling Wealth, Halving Resource Use" in 1997. More recently, Von Weizsäcker and the Natural Edge Project have shown that engineering and innovation can improve resource use and wealth creation by a factor of 5 – an 80 % improvement in resource productivity (von Weizsäcker et al. 2009). At a time of increasing concern over climate change and ongoing economic focus on growth, such contributions help focus attention on engineering and the wider "Limits to Growth" debate, "a green new deal" wave of sustainable engineering and technology. It is apt to recall the native American saying attributed to Alanis Obomsawin, "Your people are driven by a terrible sense of deficiency. When the last tree is cut, the last fish is caught, and the last river is polluted; when to breathe the air is sickening, you will realize, too late, that wealth is not in bank accounts and that you can't eat money."

Humanitarian Engineering, Technology and Development

Engineering applications and innovation for humanitarian development include all levels of technology, from low to high. Technology should reflect social need, affordability, operability, maintainability, sustainability – for example from higher tec solar PV systems to medium and lower tec, such as foot-operated water pumps for African farmers (an innovation is a technology that is new to the user or user-group). The crucial consideration is that technology should be appropriate to social, economic, environmental, engineering and technological context. For a background to appropriate technology see "Small is Beautiful" (Schumacher 1973). Interest in engineering and technology for development has waxed and waned over the last 50 years, with increasing interest in appropriate technology in the 1960/70s. Interest declined in the 1980s/1990s with changing politics, cuts in aid in many Western countries and linkage to policies of structural adjustment. There was a reemergence of interest in appropriate technology in the 2000s, reflected, for example with the publication of "Small is Working" (UNESCO, ITDG, TVE 2004), establishment of Appropedia (2006) and the development of Engineers Without Borders groups around the world. Appropriate technology is not therefore dead (Paul Polak 2010), but resting. Appropriateness is also a feature of new modes of knowledge generation and dissemination, networking (sixth wave of innovation), sustainability, greener engineering and cleaner technology for climate change mitigation and adaptation (seventh wave).

Engineering and engineering education is vital to the sixth and seventh waves of innovation, in developed and developing countries – where much of the technological, economic and social change will take place. This relates to a "political economy of engineering and development" – in developed and developing countries engineering applications and technology depend on knowledge, resources and funding, and in less developed countries also includes development assistance. The contribution of engineering and technology to development depends on various considerations, internal and external to engineering. Considerations external to engineering include awareness of the role of engineering/technology in development and the need for appropriate policy and implementation by policy-makers and decision-takers. Considerations internal to engineering include the need for information and advocacy regarding the role of engineering in development, and the inclusion of development issues in engineering education.

Various factors for success relate to the application of engineering and technology for humanitarian development, these include the need for:

- Information, advocacy, resources, leadership
- Appropriate policy, need for commitment, implementation of policy
- Technologies to be appropriate to local social and economic needs conditions affordable, operable, maintainable, sustainable
- Engagement and involvement of local community and engineers
- Drive by the engineering and technology community, popular champions
- Focus on various communities: engineering organisations and education institutions policy, planning, development in government and private sectors
- NGOs, international and intergovernmental organisations

Issues, Challenges and Opportunities – Fun and Fundamentals

As noted above and in the UNESCO Engineering Report (Marjoram 2010, in UNESCO Report 2010), particular issues and challenges for engineering include:

Decline of interest and enrolment of young people in engineering
Shortages of engineers, technologists and technicians
Brain-drain of engineers from developing countries
Need for investment in infrastructure, capacity and R&D
Climate change, mitigation and adaptation, move to lower-carbon future

The decline of interest and enrolment of young people (especially women) in engineering appears mainly due to negative perceptions that engineering is uninteresting, unappealing, uncool and boring, that university courses in engineering education are difficult and hard work, that engineering jobs are not well paid, and that engineering has negative environmental impact. There is evidence that young people turn away from science at age 10–12, that good science education at primary/secondary level is vital, and that teachers can turn young people on and off science and engineering (National Science and Technology Centre Australia 2007). The image of the nerdy engineer is epitomised in the "Dilbert" newspaper cartoon, and by Mr Bean (although Rowan Atkinson has a degree in engineering). The overall message is that engineering is uncool. Many countries report shortages of engineers, and many Western countries solve this problem through immigration from developing countries, although from the developing country perspective this is brain-drain, and has a serious impact on capacity and development in those countries. Such brain-gain may therefore be considered unethical, where a better 'engineering' solution is to enhance enrolment in developed countries. The need for investment in infrastructure, capacity and R&D following the Global Financial Crisis in 2007–8 was emphasized by Barack Obama in the run-up to the 2008 and 2013 elections (Obama 2008, 2013).

The importance of engineering in climate change, mitigation and adaptation, and the move to lower-carbon future, elsewhere in this chapter.

To address this situation there is a need to counter specific negative perceptions of engineering as unappealing, boring and uninteresting, and a need to promote public awareness and understanding of the important role of engineering in development. To counter the perception that engineering education and university courses are hard work there is a need to make education and university courses more interesting and relevant for problem-solving, that emphasise a problem-based learning (PBL) approach. To counter the perception that engineering jobs are not well paid there is a need to promote the perception of pay parity with similar professions and levels of qualification (although, following supply and demand, salaries are increasing in areas of shortage). Finally, to counter the perception that engineering has a negative environmental impact, there is a need to promote engineering as a part of the solution to sustainable development, climate change reduction and mitigation, rather than part of the problem. To sum up, there is an ongoing need to address and present an overall picture of engineering to:

- Emphasize engineering as the driver of social/economic development to get engineering on the development agenda
- Develop public and policy awareness of engineering
- Develop information on engineering highlighting the need for better statistics and indicators on engineering
- Promote change in engineering education, curricula and teaching to emphasize relevance and problem-solving
- More effectively apply engineering to global issues such as poverty reduction, sustainability and climate change
- Develop greener/sustainable engineering and technology – the next wave of innovation

The promotion of relevance and engineering problem-solving to address global issues such as poverty, sustainability and climate change is exemplified in such initiatives as the Daimler-UNESCO Mondialogo Engineering Award that ran from 2003 to 2010, attracting 10,000 student participants from 100 countries (Mondialogo 2010). The Mondialogo Engineering Award was a problem-based, project-design exercise involving international student cooperation focused on global issues. The interest in such issues is also reflected in the rapid growth of Engineers Without Borders (EWB) groups at universities around the world over the last 20 years. EWB groups have been shown to attract students, and several universities have supported EWB groups in the enrolment and retention of students. Such activities promote engineering and appropriate technology as highly relevant in addressing global issues, ensuring positive feedback, promoting public interest and understanding and conveying the important overall message that engineering is cool.

It is also useful to note that these remarks regarding engineering are part of the wider picture regarding perceptions of recent trends in academia relating to declining standards and funding, and the increasing overloading of academics. These trends have been linked to increasing bureaucracy, corporatisation, and focus on public relations, revenue, efficiency, profile and position – based on indices of academic ranking (Hill 2012).

Many of the above issues, challenges and opportunities facing engineering are linked in the provision of positive solutions. When young people, the public and policy-makers see that engineering is a major part of the solution to global issues, their attention and interest is raised and young people are attracted to engineering. They are also attracted by innovative pedagogical approaches, such as problem-based learning, and to relevance in relation to addressing global issues, such as the use of appropriate technologies to enhance sustainability and reduce poverty. There is therefore a need to promote transformation and innovation in engineering education, that includes theory and practice that was a core of the original Humboldt model – to promote fun and fundamentals.

Innovation and Transformation of Engineering Education

The main goals of innovation and transformation in engineering education to address the issues and challenges noted above are to respond to rapid change in knowledge production, dissemination and application, and the need to move from the traditional, formulaic, engineering curricula and pedagogy toward a cognitive, knowledge-based approach. This approach emphasizes experience, problem-solving and insight, with a more just-in-time, hands-on approach, and is exemplified by project and problem-based learning. This also responds to the changing need for engineers to be better attuned to knowledge change in terms of synthesis, awareness, ethics, social responsibility, experience, practice, applications and intercultural sensitivity. Due to rapid change in knowledge production and application, there is an increasing need for engineers to learn how to learn, in terms of lifelong and distance learning, continued professional development, adaptability, flexibility, interdisciplinarity and multiple career paths. There is also the need for relevance regarding pressing global issues and challenges – including poverty reduction, sustainability (environmental, social, economic and cultural), climate change mitigation and adaptation. As noted above, these needs are reflected in the graduate attributes of the Washington Accord.

Engineers are problem-solvers and innovators, and need to innovate in engineering education toward a curricula focused on project and problem-based learning, with particular reference to real world, relevant issues and problems, cleaner and greener engineering and technology appropriate to social, economic, environmental and cultural context. Curricula need to reflect formal and informal learning trends, especially the use of ICT resources for student-centred learning, with limited lectures and staff acting more in a role of learning facilitators. There should be a focus on development and the assessment of graduate attributes, and the provision of suitable learning and work space to facilitate student interaction. The focus on real world, relevant issues and problems also serves to promote engineering as essential, exciting and a rewarding career (Beanland 2012).

Innovation and transformation is a socio-political as well as a technical process, and as such may encounter barriers and resistance to change. In general, universities and academics have a focus on research, rather than education, are conservative and resist change, and have a culture and space for lecturing, rather than learning. Universities focus on staff performance in terms of papers published and grants gained, and have higher rewards for researchers than effective educators, and university leaders rarely see the need for transformation. Other barriers and resistance relate to accreditation authorities, who also tend to be conservative, slow to change, often averse to an output-oriented, graduate attribute approach, and may not effectively enforce attribute achievement at the individual student level. This is not always the case, however, and accreditation authorities may lead and be instrumental to and noteworthy champions of change, as is the case with many members of the Washington Accord. Despite the rhetoric of excellence, quality, innovation and creativity noted above, however, there are also real concerns regarding declining standards in these areas.

Transforming Engineering Education

There is an increasingly urgent need to transform engineering education to address points raised above – to address shortages of engineers reported in many countries, to move with changing modes of knowledge production, dissemination and application, and in recognition of changing needs for engineers, in terms of knowledge, learning, graduate attributes and professional competencies. These include a problem-solving, problem-based learning approach and link to global issues – poverty, sustainability, climate change. There is an associated need to promote information, evidence, examples of good practice and advocacy on the need to transform engineering education, targeted at engineers, engineering organisations, accreditation bodies, universities, decision takers, policy makers and governments, to emphasise the need for change, facilitate support and enlist champions for change and transformation.

Various 'transformative actions' are of vital importance for change, and it is possible to identify areas of transformative action that are crucial for change in the transformation of engineering education (UNESCO Report 2010; Beanland and Hadgraft 2013). These relate particularly to:

- Knowledge systems – in engineering, science, technology
- Data and information – in/on engineering, science, technology
- Ethical issues – in engineering, science, technology
- Engineering and science education and educators
- Engineering profession and associated institutions
- Engineering industry, employers and associations
- Engineering and government policy and policy makers
- Society and social context for engineering, science, technology

Transformative actions require guidelines, and in the above areas this includes the need to develop and disseminate a better understanding of the knowledge system of engineering – how knowledge in engineering is produced, disseminated and applied in academic, industrial and consultancy settings, and associated social, economic and ethical contexts. This relates particularly to and underlines the need to develop engineering studies to better understand engineering, as a partner to science studies and input to policy. This requires data and information on engineering, in this case to support evidence-based advocacy for change. This needs to be directed toward engineering and science educators (at tertiary and secondary level), the engineering profession, institutions and industry, policy makers and politicians. Particular guidelines for transformative actions include the following:

- Use of the Washington Accord graduate attributes as overall objectives for engineering education, with assessment based on these attributes.
- Design and use of curricula based on Washington Accord graduate attributes to establish student goals and develop professional competencies
- Emphasis on student-centred, problem-based learning and ICT resources, as an alternative to lectures, to encourage motivation and engagement, especially in the first year
- Use of student learning rooms, personal learning environments and e-portfolios, staff operating more as learning facilitators than lecturers
- Use of projects focused on real-world needs to develop design skills, teamwork and communication (such as the Mondialogo Engineering Award, EWB Challenge in Australia).
- Development of university-industry cooperation to facilitate project activity, work and professional experience, staff exchange and promotion of engineering as a career.

Barriers and resistance to change may be overcome with various strategies. The university and academic focus on research needs to be addressed with more emphasis on and reward for educational activity. The conservative nature of universities in relation to pedagogical change can be addressed with information and advocacy for change. One of the main concerns here relates to the belief of many academics that problem-based learning takes more time and effort than conventional lecturing – which is not necessarily the case. The university focus on lecturing persists, to the extent that some academics regard lecturing as synonymous with learning. The validity of such a perception can be reviewed by research and information on learning. PBL emphasises learning, and Aalborg PBL graduates, for example, are sought after by industry for their initiative and innovation. University space has generally been designed for lecturing, although many universities are realising and addressing the need for student learning areas. While some accreditation authorities may still be conservative and reluctant to change, many recognise the importance of the graduate attributes of the Washington Accord and are leading champions of change.

Engineers and educators can help facilitate change by recognising, supporting and promoting the transformation of engineering education to universities and government through example, research, information and advocacy. They can work with accreditation authorities and universities to implement Washington Accord graduate attributes, professional competencies and development. They can also work with industry on projects, professional experience and staff exchange to facilitate transformation.

Concluding Remarks

Transformation and change in engineering education is required to attract and retain young people to engineering, to address reported shortages of engineers around the world, and associated brain drain from developing countries, and to keep up with changing needs for engineers, changing modes of knowledge production and application and changing global needs. These include the increasing need for sustainability, climate change mitigation and adaptation, and humanitarian engineering to reduce poverty and promote social and economic development – challenges that concern and appeal to many young people, and attract them to engineering. The transformation of engineering education needs to be student-centred, with a focus on graduate attributes, professional competencies and relevance. This transformation will not only benefit students and engineering, but also universities, industry and the wider public. Other professions, such as medicine, have transformed toward 'patient-based' learning, when there was no enrolment need to do so, whereas engineering has enrolment and retention issues that transformation will address. These issues are internal and external to engineering, and require internal and external incentives to change, including a move from teaching to learning, and a better balance of reward between learning and research at universities. Student-centred, problem- and project-based learning has been shown to facilitate such transformation at universities around the world (including Aalborg, Olin College and Singapore University of Technology), with many other universities taking increasing interest. Accreditation authorities and governments need to recognise, support and help facilitate the output-oriented, graduate-attributes approach and transformation of engineering education.

There is a particular need to recognise the changing context of knowledge production and application, and changing needs for engineers in terms of learning, graduate attributes and professional competencies, as indicated in the Washington Accord. These include a problem-solving, problem-based learning approach and link to global issues – especially poverty, sustainability and climate change. There is also a need to develop and promote information, evidence, examples of good practice, and to enlist champions for advocacy regarding the transformation of engineering education, focusing on engineering organisations, accreditation bodies and universities, with the goal of facilitating government and private sector support for transformation. To conclude, it is useful to consider the consequences of failure in addressing the need to transform engineering education – continued and increasing shortages of engineers around the world, continued brain drain and impact on social and economic development, especially in developing countries, a world of increasing borders without engineers. This is the backdrop to the need for engineering education to transform itself to interest, promote enrolment and retention of young people, reflecting changing knowledge, production, dissemination and application, changing societal and economic conditions and needs.

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