Problem-Based Learning, Engineering and Technology for Sustainable Human Development

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Aalborg Centre for Problem Based Learning
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UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE BOGOTÁ
FACULTAD DE INGENIERÍA

"Problem-Based Learning, Engineering and Technology for Sustainable Human Development"

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Abstract

There are shortages of engineers in many countries, especially in some fields of engineering, un- and underemployed engineers in others. In these situations it is important that engineering education attracts and retains young people, and gives them skills and competencies that promote employability, enterprise and entrepreneurship. As people learn best when they are enjoying the learning process, engineering education should include fun as well as fundamentals, and learning how to learn for continued professional development, in line with professional attributes and competencies such as those of the Washington Accord. The optimal pedagogical approach for the problem- and project-based profession of engineering is problem and project-based learning. Given the present and future need for sustainable environmental, social, economic and humanitarian development, climate change mitigation and adaptation, and engineers with competencies in these fields, engineering education will need to focus increasingly on technology that is appropriate to these contexts and needs. Young people are attracted to action to address such global issues, and are attracted to engineering when they see its relevance in sustainable and humanitarian development, in an educational approach based on problem and project based learning. This paper discusses these issues, with particular reference to required attributes and competencies and examples of problems and projects in sustainable and humanitarian development that have been proposed to address them in such activities as the Daimler-UNESCO Mondialogo Engineering Award, an award-winning activity that ran from 2003-2010, involving over 10,000 young engineers from over 100 countries, and groups such as Engineers Without Borders around the world.

Keywords: Engineering education, transformation, PBL, sustainability, human development

Type of contribution: Conceptual/ position paper

1 Introduction

In engineering and engineering education a recent interest in many countries has been on addressing reported shortages of engineers, and how to get more young people into engineering, especially young women. This has focused on the promotion of women and inclusion of minorities that are under-represented in engineering, and other 'STEM' subjects. It is becoming clearer that an overall shortage of engineers is part of the picture at the bigger, aggregate level, with more detailed analysis indicating that this perception related mainly to some fields and levels of engineering, and in some locations, wheras there was an increasing awareness of underemployment and unemployment in other fields, levels and locations. This is possibly as a result of over-supply in trying to address overall shortages over the last decade, possibly also resulting from changes following the Global Financial Crisis of 2007-8, from globalisation (for example, increasingly global companies outsourcing services such as design and relocating whole factories overseas), wider technological innovation and change and, in Australia for example, the mining industry boom and its current decline (the mining boom itself caused economic distortions that lead to the demise of other industry, for example automobile manufacturing). In Australia, an increasing proportion of graduate engineers have difficulty finding appropriate employment, caught in the catch-22 of having little experience that employers prefer. They are consequently obliged to accept lower positions than hoped for, and may be encouraged to identify opportunities and create start-up consultancies and companies. This relates particularly, for example, to areas of civil engineering (affected by lower infrastructure investment, and globalisation), mechanical engineering (industrial relocation and outsourcing) and electrical/electronics engineering – where young engineers have created renewable energy start-ups in an atmosphere of government policy paucity and climate change scepticism. It is also linked to Department of Employment data showing little skill shortage in engineering since 2012-13, although engineers continue to be included on the Department list for approved professional migration (for which Engineers Australia, the national institution for engineers, receives an assessment fee – also creating conflict of interest issues), and also to the contentious policy of issuing skilled temporary visas for overseas engineers. This situation also reflects the need for better statistics and indicators on engineering education, resources and needs in most countries, as part of the need for better numbers in science and engineering (Marjoram, 2015/2).

Apart from the Australian mining boom and its decline, the challenges facing engineering education are common to many countries, rich and poor. For example, in Timor Leste, a developing country to Australia's north recovering from the aftermath of 25 years of Indonesian occupation from 1975- 1999, graduate engineers find difficulty getting jobs because of limited employment and an employer perception that they are too theoretical and hands-off, with little practical or teamwork experience. This reflects an approach to engineering education based on the Indonesian traditional theory- and teacher-lead model at the University of Timor Lorosa'e, which was established as an offshoot of Gajah Mada University to train secondary school teachers, administration and agricultural extension workers - where research, analytical and critical thinking was not supported. As a Timorese Master's student of engineering in Sydney has observed, "There is a huge difference between studying in Australia and studying back home in Timor Leste, because in Australia students are independent and encouraged to be active, whereas in Timor students are expected to just listen to the teacher. We also have a lack of facilities in East Timor and so students find it hard to achieve what they want" (Da Silva, 2013).

2 Engineering and engineering education

Engineering and engineering education today are as they are due to a mixture of technical, cognitive-educational and socio-professional factors – prior engineering and technological innovation and change, prior approaches to engineering education, and the changing role of engineering and engineers in society.

Engineering has developed through the successive waves of technological innovation, from the first wave technological change in the Industrial Revolution of 1785-1845 – 60 years of development, particularly of iron, water power and mechanization. The second wave of technological innovation from 1845-1900 saw the rise of steel, steam power and the railways, over around 55 years. The third wave of technological innovation from 1900-1950 witnessed the development of electricity, chemicals and the oil industry, heavy engineering and the internal combustion engine over a period of 50 years. The fourth wave of technological innovation from 1950-1985 saw the development of automobiles, petrochemicals, electronics and aerospace over 35 years. The fifth wave of technological innovation from 1985-2005 saw the growth of computers, ICT, information societies and economies over around 20 years – in increasingly shorter periods, from what was a lifetime to less than a generation. The sixth wave of technological innovation (2005-25?) is seeing the further development of new knowledge and applications in the areas of ICTs, biotechnology, nanotechnology, materials technology, robotics and sustainability. The increasing emphasis on sustainable development, climate change mitigation and adaptation will continue into a seventh wave of cleaner/greener engineering and technology, albeit against some populist feelings of climate change and knowledge skepticism. These Kondratiev waves of technological innovation and revolution have seen new modes of knowledge generation, dissemination and application in increasingly knowledge- and information-based societies and economies. These changes have primarily been from "Mode 1" disciplinary knowledge systems to "Mode 2" interdisciplinary knowledge systems (Gibbons et al, 1994; Nowotny et al, 2001). New areas of knowledge such as ICTs and biotec are typified by innovation and interdisciplinary cross-fertilisation and fusion, with the rise of new areas and decline of old disciplines. Kondratiev waves of innovation are presented below (Von Weizsäcker et al, 2009).

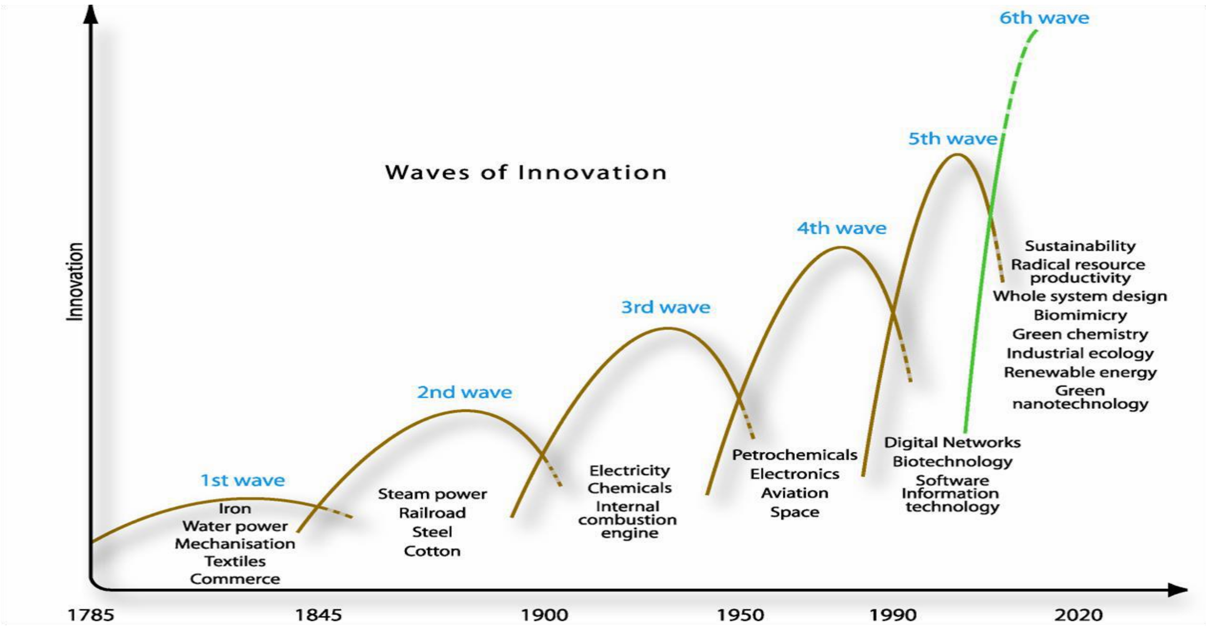


Figure 1: Waves of innovation - Kondratiev waves

3 Engineering education

New modes of knowledge production and application see new needs and new modes of learning (Beanland and Hadgraft, 2014). Engineering education has itself evolved from craft-based learning in the early industrial revolution, with an activity-based, hands-on learning approach, following a Pre- Renaissance separation of knowledge/science and practice/technology. This was succeeded into the second wave of industrial innovation and change by more formal apprenticeships, trade and skills- based, again with an activity-based, hands-on learning approach, coupled with the development of analysis and theory in the post-Renaissance growth of classical science and increasing science-base to engineering. This development continued with the growth of formal schools, colleges and universities, following the establishment of the University of Berlin, the 'Mother of modern universities' by Wilhelm von Humboldt in 1810, creating the "Humboldt model" of engineering education based on theory and practice. As schools, colleges and universities of engineering and technology developed into the 20th Century, so did 'engineering science' and the development of professionalization and disciplinary formation within engineering and of engineering education and accreditation, with an increasingly science-based, theoretical and a hands-off learning approach – with the decline of the practical element of the Humboldt model. The development of 21st century, post-industrial science and engineering has seen the further erosion of separation between science and engineering, with the growth of interdisciplinary cooperation, integration, networking, systems approach and fusion of science and engineering, with an increasing focus on synthesis, applications and problem-solving.

This has created the need for new educational approaches for the present and next generation of engineers, of education for real world practice and application, based on real world issues and challenges such as climate change, sustainable development, poverty reduction and enhancing the quality of life in developing countries. New educational approaches overturning the traditional teacher-centred approach based on student centred learning combining theory and practice, blended learning, teamwork, continued and lifelong learning. Many focus on problem-solving through project and problem-based learning, following such exemplars as the Aalborg model of PBL, the Conceive Design Implement Operate (CDIO) approach and, most recently, flipped classrooms - reversing traditional learning with online instruction and classroom exercises (not unlike aspects of PBL).

4 Appropriate engineering education – Problem-Based Learning

Core principles of problem-based learning are based around problem orientation, project organisation, integration of theory and practice, participant direction, team-based approach, cooperation and feedback, and can be summarised as follows:

- Problem orientation

  Guided problem analysis/solving - basis for learning Project organisation
- Projects guide problem analysis to reach educational objectives Integration of theory and practice

  Students see link between theory and practical knowledge Participant direction
- Students define problem and make decisions on project work Team-based approach

  Most problem/project work is in groups of 3 or more students Cooperation and feedback
- Peer and supervisor feedback and reflection important in PBL

Problem-Based Leaning is a learning approach that is essentially student-centred, as opposed to teacher-centred in traditional pedagogy, focusing on student learning needs in terms of maintaining the balance and link between theory and practice of the Humboldt model, based on real-life problems. PBL is also project-organised education, with project work supported by lectures and courses, in the context of group or team work in groups of 4-6 students, with staff playing a mentoring supervisory role. PBL may also combine interdisciplinary studies, further integrating theory and practice and a focus on learning to learn and methodological skills, and may be a faculty or university-wide model (as is the case at Aalborg, with faculty variations).

The theoretical background to PBL is that PBL focuses on learning rather than teaching, active learning rather than passive, which is fun, as opposed to traditional teaching, which involves listening and memorising, which is not fun, assessed on the ability to produce and use knowledge.

Knowledge development takes place in collaborative student groups, with staff support, and focuses on learning to develop knowledge. Interest in PBL began in the 1960s-70s, with the development of new universities in around the world and interest in new ways of learning (Kolmos, Krogh and Fink, 2004; de Graaff and Kolmos, 2007; Du, de Graaff and Kolmos, 2009; Barge, 2010).

5 Engineering accreditation - Professional attributes and competencies

A focus of interest in engineering education and accreditation has moved away from engineering curricula to professional attributes and competencies. This is reflected in the work of the International Engineering Alliance – a global group from 30 developed countries with agreements covering the recognition of engineering educational qualifications and professional competence. The IEA includes the Washington Accord - an international accreditation agreement between national accreditation bodies. Interest includes the need for new educational approaches for the present and next generation of engineers - what engineers do we need, will we need? This in turn includes the need for cleaner and greener engineers with background attributes and competencies to deal with problems of climate change mitigation and adaptation and broader issues of sustainable development, new areas of engineering and technology such as robotics and the fact that change has become a constant rather than an exception. In this context there is a need for engineers, and engineering education to respond to rapid change in knowledge, learning how to learn for lifelong and distance learning, continued professional development in a cognitive, knowledge-based approach, which will require adaptability, flexibility and intercultural interdisciplinarity for multiple career paths, requiring experience and competence in terms of understanding, insight, awareness, analysis, synthesis, ethics and social responsibility for practical applications and problem-solving.

These needs and qualities are reflected in the twelve key graduate attributes and professional competencies identified by the Washington Accord (Washington Accord):

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

As is evident, less than half of these criteria relate to the "old" engineering curricula, with the majority relating to contemporary and emerging needs of professional practice. All are ideally suited to problem- and project-based learning, as originally outlined by Wilhelm von Humboldt, combining theory and practice.

6 Engineering and sustainability

Key elements of sustainability are identified in the UN Global Goals for Sustainable Development, "Transforming our world: the 2030 Agenda for Sustainable Development", following the eight UN Millennium Development Goals 2000-2015. The Sustainable Development Goals (SDGs) consist of seventeen goals, 169 targets and 304 provisional indicators. The seventeen SDGs are for no poverty; end hunger; good health and well-being; quality education; gender equality; clean water and sanitation; affordable and clean energy; decent work and economic growth; industry, innovation and infrastructure; reduced inequalities; sustainable cities and communities; responsible production and consumption; climate action; life below water; life on land; peace and justice, strong institutions; and partnerships for the goals. The SDGs are illustrated in the figure below:

Figure 2: UN Global Goals for Sustainable Development

6.1 The SDGs and Engineering

Engineering is of vital importance in sustainable development and a central factor in directly addressing most of the SDGs, as indicated below.

Poverty:
Engineering and technology are essential in the provision of basic services, infrastructure, income generation and humanitarian development.

Hunger:
Sustainable agriculture, food production, processing depends on engineering.

Health:
Health services, well-being and the quality of life depends increasingly on engineering and medical technology.

Water and sanitation:
Engineering and technology are central in the provision of clean water and sanitation.

Energy:
Affordable, sustainable energy, energy efficiency and renewable energy technologies are developed by engineers.

Employment and economic growth:
Engineering and technology supports economic growth and employment

Industry, Innovation and infrastructure:
Engineering and engineers drive innovation, infrastructure, industry and economic growth

Sustainable cities and communities:
Sustainable cities and communities depend on engineering, construction and infrastructure

Responsible production and consumption:
Engineering and technology underpins sustainable production and consumption.

Climate action:
Climate change mitigation and adaptation, sustainable energy and reduced emissions depend on engineering and technology.

Life below water; Life on land:
All life on Earth will depend increasing on the use of sustainable engineering and technology.

In addition, quality education will be essential if we are to enrol and train the next generation of sustainable engineers, and gender equality is important to ensure that a greater percentage of engineers are women, who also have a greater interest in sustainability. Engineering and technology are also vital in promoting global partnerships for sustainable development and in reducing global inequality. On the other hand, it is unfortunate that engineering is only mentioned specifically twice in the SDG document – in the context of scholarships to developing countries for engineering (SDG Goal 4b), and in relation to global partnerships for sustainable development (SDG Goal 17).

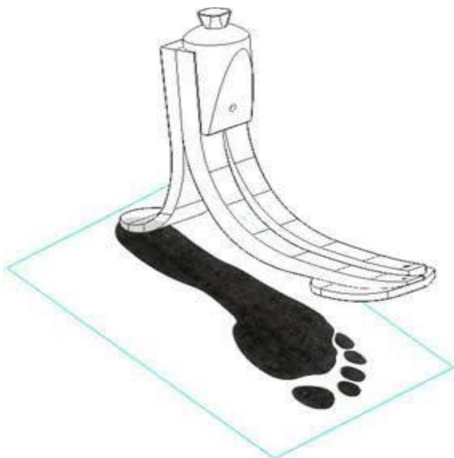
7 Appropriate engineering and technology for humanitarian development

Engineering and technology are also of vital importance in addressing human and social progress and development, and humanitarian activity in the context of post-conflict and post-disaster response, and post crisis transition and development. The SDGs should more widely be considered global goals for sustainability and development, and many of the SDGs listed above relate particularly to social, economic and humanitarian development. These include almost all the seventeen SDGs. Engineering and technology are vital in the reduction of poverty and hunger, in promoting health in such areas as water supply and sanitation and the provision of affordable housing and energy. Engineering and technology also drive industry, innovation and infrastructure, employment and economic growth (Metcalfe, 1995; Stewart, 1977). Engineering and technology underpin sustainable production and consumption and will be an essential part of the solution of climate change mitigation and adaptation and the continuation of life on planet earth.

Engineering and technology play a special role in post-conflict and post-disaster response and reconstruction, in all the areas of social and humanitarian development noted above. Engineers are usually the most immediate post-crisis responders in terms of rescue and making safe, and engineers are at the forefront of reconstruction activities. In Colombia the peace process follows 50 years of armed conflict and engineering will be vital in post crisis transition and development. East Timor became independent after 25 years of Indonesian occupation, with severely damaged infrastructure and no experience of the understanding, planning, organisation and management of development activities, particularly in rural areas, that had taken place over the same period in similar countries – such as those of the Pacific islands. Engineers with insight into and experience of technology, innovation and social and humanitarian development, and associated institutions, policies, programmes and initiatives, are vital in such situations. Examples of such humanitarian development activities include improved affordable housing building upon local skills and materials. Household water supply using roof-water catchment or slow sand filters and locally made ferro- cement or galvanised rainwater tanks. Improved pit and pour-flush sanitation. Solar PV household energy systems and improved cooking stoves. Food production and processing for household and small business development. Small scale technologies are the basis for many other small business and employment development initiatives, including chicken and livestock raising, bakeries, trades- based and workshop businesses.

The Daimler-UNESCO Mondialogo Engineering Award was an example of an international initiative promoting cooperation between engineering students to address issues of humanitarian development in developing countries, with a particular focus on quality of life improvement and sustainable development. The Mondialogo Engineering Award ran in three series, each concluding with a Symposium and award ceremony, from 2003-2010, organised by Daimler and UNESCO, and involved over 10,000 young engineers from over 100 countries. Students formed international partnerships to cooperate on problem-based, problem-solving project design exercises in humanitarian development. Projects included impressive design solutions to a diversity of humanitarian issues such as affordable water supply and sanitation systems, improved housing and household lighting systems and cooking stoves, low-cost bridges, food production and processing, telemedicine and prosthetic limbs, some of which were successfully commercialised, although this was not a condition of the competition. The Mondialogo Engineering Award was itself a multi award- winning initiative, that sadly concluded with the Global Financial Crisis (UNESCO, 2010).

Low cost bridge building – Rwanda-Germany team



Prosthetic foot – Colombia-USA team

8 Concluding remarks - transforming engineering education

Particular challenges for engineering include the decline of interest and enrolment of young people, especially women, in engineering. This is mainly due to negative perceptions that engineering is boring, nerdy and uncool, that university courses are difficult, hard work and boring, that engineering jobs are not well paid and that engineering has a negative environmental impact and image. There is also 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/off science. There is an overall need to emphasise engineering as the driver of social/economic development to get engineering on the development agenda, to develop public and policy awareness of engineering, develop information on engineering, highlighting the need for better statistics and indicators on engineering, to promote change in engineering education, curricula and teaching to emphasise relevance and problem-solving, more effectively apply engineering to global issues such as poverty reduction, sustainability and climate change and to develop greener/sustainable engineering and technology and the next wave of innovation. There is a particular need to address negative perceptions that engineering is boring, that engineering education is hard work, that engineering jobs are not well paid and that engineering has negative environmental impact and image. These negative perceptions can be addressed by promoting the public understanding and awareness of engineering, making engineering education more interesting and relevant for problem-solving (eg through problem-based learning), better understand and control the supply and demand for engineers and encouraging small engineering business development and the promotion of engineering as a part of the solution, rather than part of the problem to sustainable development, climate change reduction and mitigation.

Many of these issues, challenges and opportunities are linked in terms of providing 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 they are attracted to engineering and the relevance of engineering in address global issues humanitarian engineering. There is therefore a need to provide examples of engineering relevance in development and promote transformation and innovation in engineering education – to combine theory and practice as in the original Humboldt model, linking fun and fundamentals and demonstrating that engineering can be cool. Promoting public interest and understanding of engineering will also promote the relevance of engineering to address global issues such as poverty, sustainability and climate change. Promoting the relevance of engineering and humanitarian engineering in addressing such issues has been demonstrated in such initiatives as the Daimler-UNESCO Mondialogo Engineering Award and the many Engineers Without Borders around the world that are very attractive to students (Mondialogo, 2010).

Transformation and innovation in engineering education is important in updating engineering curricula and pedagogy to be less theory and formulae driven, involving more activity, project and problem-based learning, in more just-in-time, hands-on approaches, such as the Aalborg PBL model and related approaches. Other professions have moved in this direction – for example, medical education has moved toward more "patient based" learning. It is beyond time for engineering to do the same. The transformation of engineering education needs to address the need to respond to rapid change in knowledge, learning how to learn in a cognitive, knowledge-based approach with relevance to pressing global issues and challenges

Engineers are innovators and need to innovate in engineering education, based on problem and project-based learning for a problem-solving profession (UNESCO, 2010), linked to issues of relevance such as sustainability and humanitarian engineering and technology. In response to changing knowledge production and application, lifelong learning and continued professional development, there is a need for the increased use of ICT resources for student-centred learning, with limited lectures, where staff act as learning facilitators and mentors. There needs to be greater focus on the development and assessment of graduate attributes and the provision of learning and work space to facilitate student interaction. Transformative actions are required in the areas of knowledge systems in engineering, science, technology, relating to the social context and ethical issues in engineering and technology, improved data and information on engineering, the development of the engineering profession and organisations, engineering education and educators. The development of engineering policy, planning and decision making is also required, and the promotion of engineering as a separate but related aspect of 'STI' – SETI would be a more accurate descriptor.

Transformation and change does not come easy, however, and barriers may be encountered from people and institutions that do not see the need or rationale for change. Barriers to change in engineering educators and universities relate to the traditional focus on research rather than education that does not reward effective educators, a culture of lecturing rather than learning, space designed for lecturing, conservative attitudes resistant to change and leaders who rarely see the need for transformation. The traditional rhetoric of the need to maintain educational 'quality' is undermined by overloaded academics, declining standards and funding, increasing bureaucracy and focus on revenue, 'efficiency' and university profile, especially university ranking and KPIs (Hill, 2012). Accreditation authorities may also be conservative, slow to change from a traditional approach to one of graduate attributes and professional competencies, but – who can be progressive and drive change, for example the American Accreditation Board for Engineering and Technology (ABET) and the international Washington Accord. The failure to transform engineering education, to address the challenges noted above, will result in insufficient engineers, technologists and technicians around the world, insufficient engineering educators, consequent impact on developing countries and continued brain drain from poorer developing countries - who can ill afford to lose engineers, effectively subsidising richer developed countries, creating borders without engineers!

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