Global Engineering for a Small Planet

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Recommendations

- The engineering community should embrace global engineering as the professional and academic complement to the fields of global health and development economics.
- Global engineers are needed to address a multitude of global issues faced by humanity today and in the foreseeable future.
- Global engineers need to be able to make decisions across technical and socioeconomic and political sectors while operating in a multicultural and increasingly challenging world.
- Engineering education and practice should include introductory training in health, economics, policy and governance as relevant dimensions of engineering's contribution to achieving the Sustainable Development Goals.

Abstract. Meeting the United Nations Sustainable Development Goals by 2030 is impossible without the full input of the engineering profession. Global engineers are needed to address a multitude of global issues faced by humanity today and in the foreseeable future. To do so, they need to acquire, during their formative years and professional careers, the approaches, skills and knowledge necessary to operate in a global world. This approach responds to increasing global needs as well as demands within the engineering profession, as students desire more meaningful opportunities to apply what they learn. This chapter advances the view that global engineering functions as the professional and academic complement to the fields of global health and development economics. These fields work to improve the tools and practice of poverty reduction, including health, economics, policy and governance as relevant dimensions, and require engineering professionals to be conversant in these fields.

A new engineering mindset

To address the global issues faced by humanity today and in the foreseeable future, the engineering profession needs to revisit its principles, practices, and research and development priorities. A new form of engineering education and practice is urgently needed – one that is based on an awareness of the impact of engineering on society and the environment, social and community engagement, leadership, teamwork, reflective and adaptive practice, combined critical and creative thinking, field exposure to global problems during students' formative years and professional careers, and lifelong learning. This new form of engineering education and practice must be designed with the overarching goal of forming *global engineers* capable of making decisions across technical and socioeconomic and political sectors while operating in a multicultural and increasingly challenging world.

To quote Albert Einstein, ‘the significant problems we face today cannot be solved at the same level of thinking we were at when we created them’. The education of a new generation of global engineers able to work across disciplines, cultures and community needs does not come without its own share of challenges. However, these challenges have precedents in previous changes that have shaped the engineering profession and its relationship to society over the past 200 years. For example, during the first part of the nineteenth century the dominant view held that engineering should develop apart from society and that technology was nothing more than applied science and economics, an approach that was termed internalist or determinist by science historians (NAE, 1991). The first quantum leap to change the dynamic between technology and society and shape the engineering profession took place during the second half of the nineteenth century and the first half of the twentieth century. The period from 1850 to 1950 is often regarded as the first Golden Age of engineering. During this time the importance of engineers and their contribution to society was unquestioned (Florman, 1994). Technology in the Western world meant material progress at all costs and ‘maximization of profits for owners and stakeholders’ (Huesemann and Huesemann, 2011). As Schön (1983) notes, the thinking behind engineering practice and education at that time was based on technical rationality – the solving of well-defined problems following the deterministic attitude of the nineteenth century. This mindset helped to define ‘the proper division of labour between the university and the professions’ in the Western world and the ‘split between research and practice’ (ibid.). It also helped to craft the concept of the ‘expert’ as one who focused on narrowly technical practice. However, these experts were not supposed to include socio-economic, political, and environmental factors and values in their technical decisions.

It is interesting to note that the perception that engineers are solutions-oriented people is still dominant in society today. Society expects engineers to identify a service or product need and to design technical solutions to address that need: mission accomplished.

This model has indeed been useful in high-income regions where the engineering profession is complemented by a strong tax base leveraged to provide essential government services such as water, sanitation, electricity and roads; an enforced regulatory environment to maintain the quality and safety of these services; and business and consumer markets that pay for products and services. These complementary facets of society are largely invisible to most engineers since engineering education does not typically encourage students to take courses in economics, governance, business or public health in their formative years. As a result, engineers are poorly equipped to address or even recognize structural and policy gaps when they exist in settings other than those found in high-income regions.

The second quantum leap that changed the dynamic between technology and society and shaped the engineering profession took place in the 1960s, 1970s and 1980s, and was associated with the environmental and sustainability movement born out of the publication of *Silent Spring* (Carson, 1962), *The Limits to Growth* (Meadows et al., 1974) sponsored by the Club of Rome and *Our Common Future* (WCED, 1987) produced by the Brundtland Commission. However, it took until the mid-1990s to early 2000s for industry to consider and partially endorse the value proposition of sustainable development defined by the Brundtland Commission as ‘development that meets the needs and aspirations of the present without compromising the ability of future generations to meet their own needs’.

In 1992, the United Nations Conference on Environment and Development, also known as the Rio Summit, helped to pave the way for many issues that are still of concern today in the areas of economic development, climate change and poverty reduction. A significant outcome of the Rio Summit was the publication of Agenda 21 (UNCED, 1992), a blueprint for actions to be taken in all aspects of human activities. The Rio Summit exemplified the critical role played by science, technology and engineering (STE) in shaping future societies and the health of the planet in general.

The Rio Summit and subsequent initiatives such as the Millennium Development Goals (MDGs), the Sustainable Development Goals (SDGs) and the Global Grand Engineering Challenges,[1] endorsed by several engineering academies in China (CAE), the United Kingdom (RAE) and the United States (NAE), have created a platform for a renewed sense of purpose for the engineering field. As remarked by Bugliarello (1991), ‘today, engineering has an unprecedented opportunity to exercise leadership in showing how technology can offer the means for creating a better world, out of the ashes of collapsing or obsolete political and economic systems’. This statement is more relevant today than ever, and if acted on could support a new vision and rebranding of what engineers do – one that is broader, more global facing and potentially more relevant to a younger generation. Such a transformation could also help to increase programme enrolment (Moskal et al., 2008).

At the end of the second decade of the twenty-first century, a third quantum leap likely to shape the dynamic between technology and society and the engineering profession is on the horizon. The engineering profession is being challenged to address highly complex issues related to rapid population growth, urbanization and climate change. Over the next two decades the global population is expected to rise by 1.5 billion people, 97 per cent of whom will be born in developing regions or states currently classified as least developed countries (UNDESA, 2006). Population growth combined with a worldwide increase in food and energy prices has forced the international community to consider more closely the links between water, energy and food resources (Dresden Nexus Conference 2015). By 2050, global food demand is expected to grow by 60 per cent, energy

[1] See www.engineeringchallenges.org.

demand by 80 per cent and water demand by 55 per cent (Ferroukhi et al., 2015). This growth will occur in an already existing context of uneven resource scarcity in which the consumption of water, energy and food resources are interconnected. In addition to meeting the demands associated with population growth and providing the necessary infrastructure, other issues affecting human and economic development include increasingly competitive demands for water, energy and food resources, both within and across various sectors (domestic, industrial and agricultural), and demands from groups of consumers who may or may not be on different sides of a geopolitical border (*The Economist*, 2019). If resource allocations are not adequately addressed, compromises in the development, management and allocation of natural resources across groups and sectors have the potential to create unintended negative consequences, risks and uncertainties that could adversely affect large populations, especially those living in poor and marginalized communities.

Climate change is another critical factor for human and economic development, as it exacerbates inequity and accelerates poverty in some regions of the world. The World Health Organization conservatively projects over 250,000 additional deaths each year between 2030 and 2050 attributable to climate change-driven increases in temperature (heat waves), diarrhoea, malaria and malnutrition (crop failure) (WHO, 2018). An additional 100 million people could be pushed back into poverty by 2030 because of climate change (Haines and Ebi, 2019). Most of these deaths and hardships will be experienced in developing countries – those least equipped to manage climate change and least responsible for its causes. Engineers have a critical role to play in developing solutions for climate change mitigation and adaptation and to contribute to disaster risk reduction.

In general, the role of engineers will be critical in fulfilling the above-mentioned demands at various scales and settings, ranging from small remote communities to large urban areas such as megacities. A key task at the heart of the SDG agenda is to identify what needs to be done, now and in the immediate future, for all humans to meet their basic needs (water, sanitation, nutrition, health, safety, meaningful work, etc.) and live with dignity and at peace. A related task is to determine how can engineers best participate in the SDG agenda and contribute to meeting the SDGs and their targets worldwide by 2030 and beyond.

Simply put, meeting the SDGs by 2030 and additional development goals beyond that date is impossible without the full input of the engineering profession – but not an engineering profession steeped in the same approaches, skills and knowledge that led to the significant accomplishments of the last century. Taking into consideration the problems facing the planet today and those expected to arise in the next 40 to 50 years, the engineering profession must reassess its mindset and adopt a new mission statement: to contribute to the building of a more sustainable, stable and equitable world in all countries in various stages of development. The engineering profession faces the challenge of building on its significant achievements in the twentieth century and expanding such achievements to all humans on the planet, not just to a limited few in the developed world.

Global engineering

Guiding principles

As noted by Weingardt (1998), 'engineers are probably the single most indispensable group needed for maintaining and expanding the world's economic well-being and its standard of living'. Today, the quality of life of many societies is built upon a complex and highly productive set of technological, industrial and municipal systems and structures (see Chapter 1). Continuing discoveries in electricity, mechanics, materials, processes and testing have resulted in thousands of new products and services, all contributing to increased levels of health, comfort and productivity that were previously unthinkable. Moreover, over the past 50 years, these advances have been accomplished with surprising ease that people, specifically those living in the developed world, have been conditioned to expect solutions for any new problem or need to appear almost immediately.

In some ways, that expectation is valid. The fields of biology, computers and information technology, materials, nanotechnology and others continue to progress rapidly. New discoveries seem to appear almost every day, lending a sense of boundlessness to possible advances. However, many technological successes in the developed world have also contributed to unplanned and/or undesirable impacts on natural and human systems (Berry, 1988), resulting in criticism by society. As noted by Hollomon (1991), Bugliarello (1991) and others, these effects have forced the engineering profession to acknowledge its limitations, revisit its assumptions and realize that:

- Many engineering decisions cannot be made independently of the surrounding natural and human-made systems, because modern engineering has the power to significantly affect these systems far into the future (e.g. 30-100 years).
- Human capacity to cause planetary change through technology is growing faster than its ability to understand and manage the socio-economic and environmental consequences of such change.
- The traditional notion that engineering is a process to devise and implement a chosen solution amid several purely technical options must be challenged and replaced with one that takes into consideration the health of human and environmental systems.
- A more holistic approach to engineering education and practice requires an understanding of interactions between engineered and non-engineered systems, the inclusion of non-technical issues and a systems approach to comprehend such interactions.
- Engineers must become more involved in societal leadership and policy-making.

All these guiding principles must be considered by global engineers addressing the broad spectrum of global development challenges faced by different segments of the world's population today and in the future.

On one end of the spectrum, engineers need to address the key challenge facing the developed world of consuming less and more intelligently, while being respectful of human and natural systems. In this context, engineers are being called to develop innovative and more efficient ways of providing services and to reconsider the take-make-waste process in the production, distribution and consumption of goods and services. They also need to contemplate solutions that consider the three Ps of sustainability (people, planet and profit) and how these solutions might significantly impact social, environmental and economic systems far into the future. As discussed further in Chapter 4, innovative solutions are necessary to effectively achieve the SDGs.

Since the 1992 Rio Summit, integrating sustainable development principles into projects of different scales has been a challenge for the engineering profession. As Wallace (2005) noted, 'moving toward sustainability [requires] more or less a complete overhaul of the world's infrastructure, replacing or refurbishing existing systems with new, cleaner and more efficient processes, systems and technologies'. At the same time, some sectors of the engineering profession and society have realized that sustainability offers many social, environmental and economic benefits, since 'new world markets for sustainable engineering services are being created as industries and governments alike begin the changeover to more sustainable practices' (ibid).

On the other end of the development spectrum, engineers need to address the many challenges faced by people in the developing world. More specifically, they need to help create opportunities and find solutions that will enable populations to access the resources and skills necessary to meet their daily needs. These solutions need to consider the three Ps of sustainability but will have different characteristics from those used for the developed world. They need to be technically sound and reliable, while simultaneously viable, accessible and affordable for people with limited resources living in different contexts (urban, peri-urban and rural). This approach represents a significant departure from the one applied over the last 50 years, whereby Western solutions developed for the 1-2 billion wealthiest people on the planet were imposed on communities in the developing world. This one-way street approach to development – based on the false belief that solutions need to be bigger, faster and stronger to be appropriate – has had many unintended consequences on social, economic and environmental systems worldwide.

One of the unintended consequences of the traditional Western approach to development in the developing world has been to leave developing nations without the adequate facilities and infrastructure necessary to build sustainable economies, especially in rural areas. This dynamic can be attributed to three factors. First, when these nations acquire adequate utilities, facilities and systems upon which society depends for its normal functions, the projects are more likely to be in cities and involve substantial financial and physical capital costs. Second, the infrastructure is likely to benefit an upper class, not respond to the needs of the masses, and create environmental degradation or other unintended consequences which are often ignored altogether. Third, as noted in the first UNESCO (2010) Engineering Report, developing countries lack qualified engineers and technicians: '90 per cent of the world's engineers work for 10 per cent of the world's population' (ibid, pp. 16). While this situation has been criticized by society for at least three decades, the engineering community has had a limited role in community-based development projects that address the needs of those at the bottom of the economic pyramid. However, as noted by Radjou, Prabhu and Ahuja (2012), traditional engineering practice is not interested in small projects because they are not perceived as financially rewarding. This is unfortunate as there is considerable untapped market for sustainable solutions that can benefit a few billion customers on the planet.

In today's world, what is needed is a new mindset in engineering project delivery, one that addresses the interdisciplinary challenges involved in working in the context of developing communities and at the same time delivering socially, environmentally and economically appropriate and sustainable solutions to all. Such solutions do not need to be low-tech, as Schumacher (1973) noted in his book *Small is Beautiful*; but they do need to be appropriate to the context in which they are implemented and at the same time sufficiently high-tech to meet the demands of today's world. Examples related to communication and access to energy include mobile technologies and off-grid energy systems, among many others. There are also many examples of IT systems, sensors and satellite-based remote sensing that use advanced instrumentation technologies and Geographical Information Systems tools to monitor the state of natural systems (e.g. soils, plants) and crops and the effects of climate change on these systems. These technologies also provide tools that support environmental protection and agricultural production. Current debates about technology question the appropriateness of the importation of higher quality and lower cost products such as water filters and cookstoves at the expense of local producers, or the effectiveness of giving away these kinds of products versus charging consumers a fee.

In between communities in the developed and developing world are those that belong to emerging markets (e.g. Brazil, China and India) which are experiencing rapid economic growth. In these contexts, engineers need to develop innovative leapfrogging sustainable solutions that are conscious of previous mistakes made by the developed world and work to prevent new emerging economies from slipping backwards.

Regardless of the development challenges addressed by global engineers, engineering solutions need to consider their possible unintended impact on society (especially under-represented segments of society) and the environment. As the first UNESCO Engineering Report (2010, pp. 48) noted, 'we should ensure our innovation and design solutions meet people's needs and allow them to live the way they choose without creating a negative legacy for generations to come.' In addition, engineering projects need to be: (i) done right (technically sound) with minimum adverse effects, as expected from engineering practice; (ii) the right ones for the beneficiary populations and the environment and the context and scale under consideration; and (iii) selected for the right reasons in consultation and collaboration with the project recipients. This 'three right' project mindset needs to be adopted by the engineering profession when addressing the SDGs.

Educating global engineers

The above sections define the global context in which twenty-first-century engineers need to operate and a vision of engineers contributing to the achievement of the SDGs while building a more sustainable, stable and equitable world. However, this leads to two further questions: what should global engineering education consist of and what body of knowledge should constitute the formative and lifelong education of global engineers?

Today's engineers need to be able to demonstrate a high level of adaptation and flexibility in order to address increasingly global problems in a dynamic environment where multi-disciplinary approaches are the norm. As Reynolds (2013) remarks, today's global problems 'do not respect national boundaries and require cooperation in science and engineering to address them successfully'. Engineers must be equipped to address the formidable challenges associated with the interaction of adaptive technical systems with societal and environmental systems. Simply put, a globalized world requires the education of global engineers.

The need to educate global engineers is not new and has been discussed quite extensively in the engineering education literature around the world. Global engineering is mostly presented as an umbrella term to emphasize a need to educate more competent engineers who can work and collaborate across disciplines, show cultural sensitivity and mobility, and have acquired field experience (Allert et al., 2007; Bourn and Neal, 2008; Downey and Beddoes, 2011; Graham, 2018).

What is global engineering? Although no complete definition has ever been proposed, it is possible to derive one from the definition proposed by Bugliarello (2010) for what he terms 'Engineering for Development'. According to this author, it: 'responds to the global need for engineers who understand the problems of development and sustainability and can bring to bear on them their engineering knowledge, are motivated by a sense of the future and are able to interact with other disciplines, with communities and with political leaders to design and implement solutions'.

Another way to look at global engineering is to see it as a complement to the academic and professional fields of global health and development economics, which focus on broadly improving the tools and practice of human development, and deliberately include health, economics, policy and governance as relevant dimensions and require engineering professionals to be conversant in these fields. Global engineering can be defined as engineering concerned with the unequal and unjust distribution of access to essential services (e.g. water, sanitation, energy, food, transportation, shelter, etc.) It places an emphasis on identifying the drivers, determinants and solutions toward increasing equitable access to reliable services. Global engineering envisions a world where everyone has access to these services and resources to live in dignity and peace.

These possible definitions of global engineering help to shape the discussion around the appropriate body of knowledge for the education of global engineers. However, it is necessary to start with a few preliminary remarks. Firstly, it is important to realize that the full range of global development issues mentioned above cannot be solely addressed by technology. Simply said, if all the world's problems were just technical, they would have been solved by now. Global engineering amounts to more than developing technology to solve humanity's problems. Global engineers must be able to develop solutions that take into consideration non-technical socioeconomic, cultural and political issues that play as much of a role as technical issues in explaining the problems faced by humanity today. These solutions must also be adaptive, consider gender and inclusion issues and be equitable across a wide societal spectrum. In short, global engineers need to be well-versed in dealing with equitable, appropriate and sustainable solutions whose underlying decision-making processes will incorporate both technical and non-technical tools and cross-cultural issues. As discussed further in Chapter 6, engineers must be willing to learn new tools and acquire new skills through lifelong learning in order to keep up with constant innovations.

Secondly, global engineering does not necessarily fit into any specific branch of engineering. Simply put, no single engineering discipline could address in full the multiple development challenges associated with the 17 SDGs and their respective targets. In addition, it is time to acknowledge that there are no grand and unified solutions to the ill-defined development issues addressed by the SDGs; only step-by-step approaches that require cross-disciplinary tools are possible (Manning and Reinecke, 2016). Global engineering instead should be seen as an engineering programme or field, rather than a discipline, that cuts across different engineering silos and uses tools from different technical and non-technical disciplines. This concept is obviously disruptive to the orthodoxy of traditional engineering education which is accustomed to distinct and compartmentalized disciplines and a hierarchical structure (Bourn and Neal, 2008; Graham, 2018).

Thirdly, global engineering can mean different things to different people and may involve different forms of diversity and inclusion. It is possible to envision a portfolio of different types of global engineering education programmes based on the context (cultural, political, environmental, etc.) being addressed and the scale (physical and temporal) at which problems are being considered. For instance, a global engineering education programme interested in the dynamics at play in an urban environment will have a body of knowledge entirely different from that of a programme interested in rural planning or the management of slum areas or refugee camps. The same could be said about the body of knowledge of engineering programmes addressing issues faced by communities located in different climatic and geographic regions.

All three aforementioned remarks convey the impression that it is hard to define a common body of knowledge for the education of global engineers, or to identify what fields global engineers should master, which competencies they should acquire, and what kinds of experience they should be exposed to in their formative years and careers. To a certain extent, this is true as a common body of knowledge would have to address a wide range of issues, as mentioned above. At the same time, defining the required body of knowledge is not a random process if the education of global engineers is understood as a T-type of education with both depth and breadth rather than a traditional specialized I-type of education (Manning and Reinecke, 2016). The depth aspect of T-type education deals with technical competency and professional competency (i.e. the rigorous technical tools and professionalism commonly expected of engineers in practice). The breadth aspect concerns global competency and cross-disciplinary tools from the non-technical disciplines of health, economics, policy, ethics, governance and peace studies (see Chapter 7) that engineers must be aware of in order to address the global problems mentioned above. These tools are mostly taught in non-engineering departments and colleges.

Out of the 'why', 'what', 'how' and 'who' of a T-type engineering education, the first two are generally better defined. Regardless of the global engineering emphasis, global engineers must have acquired at least the following core competencies:

- a personal, cultural awareness and understanding of what being a global citizen means;
- an awareness of the social and environmental components of engineering decision-making;
- skills (hard and soft) and tools appropriate to tackling ill-defined world issues;
- the ability to think across disciplines and handle technical and non-technical issues that necessitate consideration of gender and populations with special needs;
- project management skills for a wide range of contexts and at different scales;
- the flexibility and resourcefulness to cope with unfamiliar equipment and approaches;
- systems thinking skills by acquiring habits (Benson and Marlin, 2017);[2]
- familiarization with objective and subjective decision-making methods;
- hands-on engineering and service-learning experience in their formative years; and
- awareness that in addition to being providers of technical solutions, global engineers are also called upon to be changemakers, peacemakers, facilitators of sustainable development and innovative policy-makers.

These core competencies can also be understood in terms of different forms of mobility (UNESCO, 2010, pp. 358), including: (i) physical mobility (travelling, studying and working abroad); (ii) professional mobility (changing jobs during one's career); (iii) social mobility (dealing with different society stakeholders); (iv) cultural mobility (interacting with different cultures); (v) trans-disciplinary mobility (dealing with technical and non-technical issues); (vi) methodological mobility (using different approaches to problems); (vii) technological mobility (using different tools); and (viii) thought mobility (thinking differently in different contexts).

[2] See the list of Waters Foundation habits of system thinkers at http://watersfoundation.org.

The 'how' and 'who' of a T-type of engineering education are more challenging to address than the 'why' and 'what'. Questions remain, for instance, regarding how to: (i) expose engineering students to real-world problems through internships, co-op programmes, fieldwork and/or outreach/service-learning activities; (ii) promote leadership and integrate social responsibility and ethics across the entire curriculum; (iii) encourage students to explore a minor around at least one global issue (e.g. human development, sustainability, peace and conflict studies, etc.); (iv) encourage traditional research-oriented and teaching-oriented faculty members to include new concepts on world issues in their work; (v) encourage more women and minority groups in STEM (or STEAM, including the arts and humanities) fields by emphasizing the societal dimension of engineering; and (vi) engage stakeholders from non-academic sectors in curriculum development. Another critical question is to determine what represents successful global engineering education and practice.

Despite the resistance of academia and the engineering profession to changing and addressing the questions mentioned above and promoting a T-type of education, several worldwide efforts and initiatives have been proposed by innovative institutions (e.g. UNESCO), professional organizations (e.g. WFEO, FIDIC), educational institutions and administrators to reconsider how to train engineers to better address the complex global issues faced by humanity in the twenty-first century. In Chapter 1 of this report, Marlene Kanga, President of the WFEO reviews several examples of agreements related to accreditation and mutual recognition across engineering educational institutions. Likewise, in Chapter 5, Annette Kolmos reviews many efforts and initiatives at the country level and provides guidelines as to the type of engineering curriculum and body of knowledge necessary to address simple, complicated and complex societal problems such as those related to the SDGs.

In the related field of service learning and social engagement, there has also been a strong push towards integrating changes into engineering education and the overall university mission (Lima and Oakes, 2006). In 2005, for instance, several universities launched the Talloires Network (Tufts University, 2013). Convened by the Tufts University's President in the United States, the Talloires Network comprises an international collection of member and institutions (379 in 77 countries as of 2018) devoted to strengthening the civic roles and social responsibilities of universities in all parts of the world. It acknowledges that academic institutions do not exist in isolation from society and have a commitment to social good. It also acknowledges that: (i) there is no dichotomy between civil engagement and excellence, (ii) the university's mandate is to educate and train responsible and dedicated citizens, and (iii) civic engagement should be a priority within research and scholarship.

An example of civic engagement and service-learning programme in the United States that emphasizes the human nature of engineering is the Engineering Projects in Community Service

(EPICS)[3] programme, which started in 1995 at Purdue University in Indiana (Coyle, Jamieson and Oakes, 2005; Lima and Oakes, 2006). It is described as 'a unique program in which teams of undergraduates are designing, building and deploying real systems to solve engineering-based problems for local community service and education organizations'. Projects can last several years enabling tasks of significant size and impact to be tackled.

Another programme that emphasizes the global dimension of engineering is Engineering for Developing Communities (EDC), launched in 2004 at the University of Colorado.[4] Recently renamed the Mortenson Center in Global Engineering, the programme has evolved from a model of scale- appropriate technology design and implementation to an emphasis on the development and validation of more broadly applicable methods, technologies and evidence generation. Areas of research include: organizational theory and systems engineering; the development and validation of water, sanitation, energy, infrastructure and agricultural technologies and methods; the design of service delivery models; impact measurement methods and technologies including instrumentation and remote sensing; and the development of standards for engineered systems applied in disaster relief.

The Mortenson Center curriculum has been recently restructured to replace four required semester-long courses that generally retained a project-level civil and environmental engineering perspective, with a series of one-credit, five-week modules. These modules include introductions to global health, development economics, development geography, remote sensing, statistical analysis, policy, service delivery and impact evaluation. A required field practicum embeds students with global development agencies for at least three months, with some students continuing to engage with these agencies for many years.

Another such programme is Development Engineering, launched at the University of California Berkeley in 2014. This programme advanced a model that links human-centred design, multidisciplinary teams, and user and community-centric engagement towards product and service design for development (Nilsson, Madon and Sastry, 2014). It is built on the premise that development engineering builds 'on techniques from engineering, development economics, behavioural science and sociology' (ibid) and designs products and services on behalf of developing countries, while addressing market barriers and institutional failures and promoting business models.

Finally, since 2000 various extracurricular and volunteer student-driven groups dedicated to addressing the engineering needs of developing communities worldwide have emerged. Examples include the Engineers Without Borders (EWB) International Network[5] which consists of 72

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[3] See http://epics.engineering.asu.edu.
[4] See www.colorado.edu/center/mortenson.
[5] See www.ewb-international.com.

national groups, Bridges to Prosperity,[6] Engineers Against Poverty[7] and Engineering World Health,[8] to name a few. These groups benefit society and the engineering profession in numerous ways, by attracting talented young individuals who are committed to the engineering profession and are likely to become new engineering leaders within five to ten years. All these programmes provide multiple benefits by exposing students in their formative years to EWB-type development projects. For instance, these projects:

- Give the students an opportunity to experience all aspects of engineering from problem identification to assessment, design, implementation and monitoring.
- Give the students an opportunity to work with professional mentors during their school year, develop good contacts within the industry and learn by doing.
- Provide the students with a direct hands-on engineering educational experience in a new and safe environment.
- Give students the opportunity to work in teams on larger projects as opposed to discipline-specific projects.
- Demonstrate to students that engineering problems can be complex and not always well-defined and can be solved in more ways than one and often require working effectively with people who think differently and have different cultural backgrounds.
- Teach students how to interact with different cultures and think 'outside the box' with limited tools.
- Train students to develop an awareness of professional ethics and the role that engineering plays in addressing community needs.

Above all, EWB-type projects give students a global national and international cultural outlook similar to traditional study abroad programmes. In addition, the projects provide a sense of belonging and engagement through teamwork, a way of expressing passion and empathy, and a societal context for their engineering work. It also gives them an opportunity to reflect on themselves, develop values, act on things they are passionate about, become good listeners, work with other professions and ultimately 'think globally and act locally'. A significant outcome of EWB-type projects has been the recruitment of more women (up to 45%), who seem to be attracted to engineering because of its social dimension. Finally, it is noteworthy that EWB-type fieldwork projects have been endorsed and supported by the engineering practice, as many companies see such activities as a pipeline for recruiting talented engineering leaders (men and women) who have been exposed to many of the components of actual project management before graduation.

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[6] See https://bridgestoprosperity.org.
[7] See http://engineersagainstpoverty.org.
[8] See https://ewh.org.

Conclusions

It is broadly acknowledged that engineers have contributed to society in terms of economic development and quality of life. However, their impact has been limited to the wealthiest segments of the world's population. Today, the engineering profession is called to address a more significant challenge – to contribute to the building of a more sustainable, stable and equitable world, not only in developed countries, but also in countries in various stages of development. This broader vision calls for a demystification of engineering practice, which traditionally provides value-neutral technical solutions to well-defined problems irrespective of the social context. Instead, engineers are called to be change-makers, peacemakers, social entrepreneurs and facilitators of sustainable development.

The sustainable human development agenda laid out by Agenda 2030 and the SDGs requires the full contribution of the engineering profession. It also calls for a new epistemology of engineering practice and education, as well as a new literacy based on the idea of reflective and adaptive practice, system thinking, engagement and fieldwork. It needs global engineers who are able to look at problems in a more holistic manner and interact with a wide range of technical and non-technical stakeholders from various disciplines and walks of life, rather than remaining in their traditional silos of expertise. The challenge faced by academia and the engineering profession, in general, is the development and implementation of an action-based blueprint for the education of engineers who over their lifetime:

- Have the appropriate skills and tools to address critical issues facing the world now and far into the future.
- Can think across disciplines and interact with others (in fields related to health, economics, business, etc.).
- Are trained to assess, design, implement and monitor projects in different contexts and at different scales.
- Are flexible and resourceful enough to deal with unfamiliar equipment and approaches.
- Are committed to lifelong learning.
- Become system thinkers willing to consider the unintended consequences of their solutions.
- Have access to contemporary technology, but have the humility to understand that the Western world does not always have all the solutions.

Not only must engineers be proficient in their craft (i.e. undertake projects right from a technical perspective), they also must be able to deliver the right projects (i.e. good for the environment and the communities that interact with that environment). The projects also must be developed for the right reasons. This 'three-right' mindset is best described in the following recommendation by Martin, Brannigan and Hall (2005): 'engineers… are responsible not only for the safety, technical and economic performance of their activities, but they also have responsibilities to use resources sustainably; to minimize the environmental impact of projects, wastes and emissions; and to use their influence to ensure that their work brings social benefits which are equitably distributed'.

Global engineering should work to understand and address the unequal and unjust distribution of access to basic services and envision a world where everyone has access to safe water, sanitation, energy, food, shelter and infrastructure, and can live in health, dignity and prosperity. As much as any other profession, engineers have an opportunity to contribute to a more just and equitable world. Human development requires a humanization of the engineering profession and the realization that engineering in that context is above all – as it has always been – about people.

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