5.2 Lifelong learning in engineering: An imperative to achieve the Sustainable Development Goals

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Abstract

Many of the 17 Sustainable Development Goals (SDGs) can only be achieved through the active participation and contribution of skilled engineers and technologists. However, the advent of new technologies, automation, demographic changes and employment mobility will require continuous reskilling on the part of the engineering profession. This will necessitate building engineering capacity, as well as a structured approach, quality assurance and accreditation to lifelong learning. This chapter analyses the current state of lifelong learning in engineering and future approaches for creating a framework for policies, infrastructure and quality assurance to help achieve the goals and targets set in the 2030 Agenda for Sustainable Development.

Introduction

The continuous introduction of new and improved technology and automation is changing the world at an exponential rate. New technologies brought about by the Fourth Industrial Revolution, which include artificial intelligence (AI), robotics, nanotechnology, 3D printing, blockchain and digital healthcare, are changing jobs, career paths and the way people work (Schwab, 2017). Recent advances in machine learning and the availability of a vast amount of data to train machines has led to significant progress in AI, often substituting manual labour with technology. Robots have replaced— and will continue to replace—human activities in many manufacturing plants. The advent of newer, sophisticated technology is replacing routine work with machines or automation, polarizing the job market in developed countries and emerging economies (OECD, 2017). While this transformation brings challenges, new job opportunities are promoting economic growth and will continue to do so. About 9 per cent of occupations in 2030 will be new and do not exist at present (Bughin et *al.*, 2018). In short, the interaction of automation with AI, coupled with demographic changes and large sectoral disruptions, are changing the nature of work in the future (Munro, 2019).

The following trends are prevalent and foreseen for the future of engineering work (Schwartz *et al.*, 2019):

- The lifespan of a working engineer has increased dramatically as human beings live and work longer. Demographically, the workforce will include a larger percentage of older adults (Jenkins, 2019).
- Engineers are switching jobs in the same organization or moving to another more frequently, thus requiring continuous reskilling and upskilling (WEF and BCG, 2018).

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- New knowledge is being created at an increasing rate and technology is evolving rapidly. Engineers and technologists need to keep up with these changes and innovations in order to remain in the workforce (DeLong, 2004).
- Engineers are working on projects that increasingly span the globe or have worldwide implications, often while working for global organizations in local settings (WEF, 2016).
- While automation is and will be able to perform many human actions, soft skills such as interpersonal communication and emotional intelligence are unlikely to be replaced by machines. Engineers and technologists alike need to learn these skills to remain relevant and employable (Bughin *et al.*, 2018).

The continuing education of engineers and technologists, otherwise referred to as lifelong learning for continuous reskilling and upskilling, is therefore a necessity.

Lifelong learning (LLL) in engineering is called by various names, the most common of which are continuing professional development (CPD) for engineers and continuing engineering education (CEE). Lifelong learning or CEE takes two forms:

1. Post-secondary degrees for working professionals, consisting of face-to-face, online, blended and hybrid modalities.
2. Non-degree certificates or courses in various modalities.

This chapter focuses on a number of aspects of LLL in engineering and technology, such as forms of LLL in engineering that have a special focus on vocational education and training in technology; the latter being more useful in developing countries, especially for achieving the SDGs and meeting their targets. This chapter also examines university-industry partnerships and the role of the private sector in defining the needs of upskilling or reskilling as these arise. The second section of the chapter charts a pathway from apprenticeship to engineering and technology careers, and refers to quality measurement and assurance of CPD programmes and infrastructure with a view to ensuring the delivery of the highest standard of continuing and professional education and advanced engineering trainings anywhere in the world with common accreditation criteria. The third section of the chapter delineates various quality assurance criteria for non-formal and formal CEE.

Forms of LLL in engineering and technology

As noted earlier, LLL in engineering may take various forms and occur at different stages of working life. This section delineates these forms and notes their various advantages.

Work-based learning as a form of CEE

Work-based learning, often called apprenticeship, is defined as a system of training in a trade or profession where on-the-job learning is accompanied by study in an educational or vocational training institution. This approach is often of value in a career pathway as it enables learners to gain a license to practice in a regulated profession. It is expected that learners in work-based learning will acquire measurable competencies that may result in certification (Krupnick, 2016).

For example, Germany has widely adopted dual apprenticeship systems as a career pathway, allowing future engineers to gain valuable experiences through a structured hands-on experience.[4] These apprenticeships are considered beneficial in engineering where professional competencies, such as technical and working knowledge, skills and aptitudes, are highly valued (Dubouloz, 2016). They can also be combined with a study programme in engineering at a university; a so-called dual study programme.

There is often a contractual pay-based relationship between the employer and the apprentice. Learners may even obtain formal degrees through the completion of engineering programmes by means of a degree apprenticeship. The student alternates between periods of work in the company and study on campus, and thus benefits from supervision and support at both academic and professional levels (Singh, 2015).

Outside of Germany, a number of prestigious schools, such as Imperial College and the École Centrale de Nantes, offer degrees based around apprenticeships. These courses range from electronic to industrial engineering and cover most engineering areas of study (EUCEN, 2019).

However, work-based learning has not been systematically adopted in developing nations, and there is a need for clear policies and infrastructure. Apprenticeships in sub-Saharan African countries are often undertaken for low-skilled work and do not result in engineering training or vocational education (Bahl and Dietzen, 2019).

Non-formal and informal (NFIF) learning for engineers

Formal learning typically leads to certification or other forms of recognition. Non-formal learning is embedded in planned activities not explicitly designated as learning (in terms of learning objectives, learning time or learning support), but contains an important learning element. It typically does not lead to certification or other forms of recognition, nor is it organized or structured in terms of objectives, time or learning support (CEDEFOP, 2014).

While NFIF continuing education of engineers is common, the identification of such acquired competencies calls for certain structured processes, such as:

- the definition of competencies that can be documented and validated;
- verification of the completion of formal prerequisites for eventual validation;
- determination of desired learning outcomes/competencies for inclusion in the system;
- decisions regarding which learning outcomes are worth documenting; and
- identification of which competencies employers want their engineers to acquire.

Although some academic institutions in the United States or France and several professional engineering organizations, including the Board of Engineers Malaysia, Engineers Ireland or the Japan

[4] See the Apprentice Toolbox on the apprenticeship system in Germany: www.apprenticeship-toolbox.eu/germany/apprenticeship-system-in-germany/143-apprenticeship-system-in-germany

Society of Civil Engineers, recognize CPD achievements, a structured process for the validation and recognition of non-degree, non-credit post-baccalaureate NFIF learning is rather rare and lacks formal quality assured procedures (Feutrie, 2012, Pardo, 2016).

The overarching aim is to have in place a system to document and validate the NFIF learning outcomes of engineers that is recognized by companies, professional organizations and society so that it contributes to increased transparency and a greater mobility of engineers worldwide. This is crucial as some world regions lack trained engineers, while qualified engineers seek placements in other regions due to unemployment.

One successful, systematic approach for engineering competency evaluation of NFIF learning is the use of an e-portfolio, as offered by the Europortfolio Competency Framework (2015), which supports the processes of competency recognition and accreditation. The e-portfolio provides an environment where engineers can:

- create a digital archive for their work;
- select specific pieces of work (hyperlinked or documents) to highlight achievements;
- set goals for future training to improve;
- share learning with others and receive reviews from peers as part of formative feedback; and
- gather evidence of learning over time, which can be presented to different audiences for validation, recognition or professional certification.

E-portfolios for NFIF learning offer a flexible yet robust system that provides an assessment of competencies. They also provide professional associations, accreditation agencies and engineers a mechanism through which engineers can showcase their knowledge, aptitudes and skills acquired through NFIF learning. In the near future, wider use of blockchain activities could aggregate e-portfolios and other credentials to form a student's personal record (Roebuck, 2019).

Assessment of NFIF learning and the FEANI card

Assessment of NFIF learning can be classified into two types: i) self-evaluation, such as a personal development plan (PDP); and ii) external assessment by professional associations who keep digital records. The latter process has been implemented by several professional organizations around the world in countries such as Australia, Ireland, Japan, Malaysia and the United States.

As the professional competencies of engineers are generally established by professional associations or chambers of commerce, it is not possible to create a common set of competencies for different countries and for different engineering specializations. To address this issue, the European Federation of National Engineering Organizations (FEANI) created the 'Engineering Card'. This provides information about the engineer, including formal education, professional experience and CEE or CPD. It defines the group of competencies that each engineer can deliver and proposes an e-portfolio system to record evidence of competencies acquired in NFIF processes. Each accreditation or professional organization can use this e-portfolio to recognize competencies acquired by each

engineer. FEANI also has a system in place for awarding CPD credits to engineers. This system is voluntary and is used by the professional organizations of FEANI members.[5]

Role of formal CEE providers

Formal CEE providers also play a role in the recognition of NFIF engineering competencies. They define the modules and courses to complement the education and training of candidates willing to reach a certain qualification. These courses often face the same obstacles as NFIF learning. As a result, quality assurance to support recognition of competencies by professional organizations has become mandatory in some countries (Werquin, 2010).

Quality assurance of lifelong learning and NFIF learning in engineering

Quality frameworks for formal education vary significantly around the world, a variability that extends to continuing education, LLL and NFIF learning. Even within countries, standards and requirements for LLL and NFIF learning from industry can differ according to national legislation and the requirements of professional associations. Additionally, funding sources and drivers for CEE vary significantly around the world. For example:

- In China, the Ministry of Human Resources and Social Security establishes the requirements for continuing engineering education, and funds the China Association for Continuing Engineering Education (CACEE)[6] to develop and deliver programmes and courses to engineers and technical professionals throughout the country; the training and the periodicity are mandatory.
- In the United States, professional societies that license engineers establish the requirements for CEE, but courses and programmes are developed and delivered by institutions of higher education, and government agencies, or companies that employ engineers.
- In the European Union, the EU Commission funds projects for universities or other organizations to develop and deliver courses and programmes.

This global diversity is problematic for engineers because it limits mobility and the acceptance of licences (FEANI, 2018).

Roles of professional societies

As Markkula (1995) noted, professional engineering societies and organizations have a responsibility to provide and validate the LLL of engineers. Ireland's CPD accreditation scheme for professionals is designed to support LLL by encouraging and recognizing the good practices used by engineers. Engineers are expected to have at least five days of formal learning each year.[7] In Malaysia, the Board of Engineers has imposed a system that is accredited by the Institute of Engineers of Malaysia (IEM).[8] Each engineer must undertake at least an annual average of 50 training hours per triennium. The Australian Accreditation system is identical to that of Malaysia, as both countries belong to APEC (Asia-Pacific Economic Cooperation), along with Canada, Hong Kong, Japan, New Zealand, Philippines, South Korea, Thailand and the United States. This group of countries decided in 2001 to

[5] For the list of professional members: https://www.feani.org/feani/membership-list-0
[6] For more information on CACEE: www.cacee.org.cn [In Chinese].
[7] For more information on CPD activities: https://www.engineersireland.ie/Professionals/CPD-Careers/CPD-activities
[8] For more information on CPD: www.myiem.org.my/content/cpd-250.aspx

adopt the CPD accreditation scheme (the Sydney Accord) and the majority have implemented the system.[9] In the United States, periodic accreditation is made by the National Council of Examiners for Engineering and Surveying (NCEES) and is referred to as Continuing Professional Competency.[10]

Roles of governments

The role of government varies with regard to providing different types of funding and support across the world. Regarding legislative frameworks, governments may establish laws implementing CPD and LLL as functions of universities for research and the training of graduates and postgraduates, or there might be a lack of interest. A recurrent political argument in this regard is that investment in human capital is vital for the economic growth and development of society and will help sustain global competitiveness (EUCEN, 2019).

Role of industry

The relationship between universities and industry is important for LLL activities. Industries typically know the competencies and knowledge needed for their workforce and search for potential employees with this acumen. Industry further provides funding for the training and education of their employees to obtain new knowledge and skills. The core competencies of universities are to discover new knowledge and deliver learning, both of which are desired by industry. Thus, successful LLL depends on strong communication between the two parties.[11]

Quality frameworks for LLL and NFIF validation

Universities use two models to provide accreditation for engineering CPD. Industries also accredit and evaluate CPD and modules or courses using their own procedures based on these two types of models:

- The first model accredits centres and providers of CPD for engineers for a certain period of time using a self-assessment system for quality management and continuous improvement. During this period, administrators of these centres and CPD provider organizations can use the assessed quality level for accreditation as an added value in annual reports to stakeholders such as provosts or rectors. This accreditation can also be used as a quality assurance stamp for potential engineering participants.
- The second model accredits single training actions or modules with benefits for engineers similar to the training actions of accredited providers.

Both models can be found around the world and the choice depends on cost, the working culture of companies and engineers, and the regulations and established procedures.[12] One example of such accreditation of centres is the Quality Program (QP) of IACEE.[13] The proposed model is based on the European Foundation for Quality Management (EFQM) and is used to improve the quality of centres through self-evaluation, external accreditation or an evaluating body (Wagenaar and Gonzalez, 2018).

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[9] See www.engineersaustralia.org.au/Training-And-Development/MYCPD.

[10] For more information about NCEES: https://ncees.org

[11] See https://about.att.com/newsroom/georgia_tech_launches_first_massive_online_degree_program.html

[12] See the example of the EU/US Atlantis Programme: http://daete.up.pt

[13] Read more about IACEE's Quality Programme for Continuing Education: www.iacee.org/iacee_quality_program.php

Recommendations

Three recommendations that warrant further work are outlined below. The rapid pace of new knowledge creation taking place around the globe will necessitate that these recommendations remain agile and subject to modification.

1. *Create a global working group*. It is recommended to convene a global working group of both academia and industry to enable the identification and gathering of existing practices for the lifelong education of the engineering workforce and related fields. A U.S. National Academy of Engineering report (Dutta, Patil and Porter, 2012) first shed light on this issue. Furthermore, the group could recommend a methodology and process by which engineering lifetime learning credits are captured, validated, shared and considered for acceptance by governance bodies around the globe. This process should focus on the lifetime education standards needed for engineering and related fields. If UNESCO, in partnership with leading engineering professional societies such as CACEE, IACEE, the American Society for Engineering Education (ASEE) and the European Society for Engineering Education (SEFI), calls for such a group, their responses will help mobilize these efforts.
2. *Reduce or remove real and perceived barriers*. The working group will need to consider the real and perceived barriers to achieving a globally available and accepted lifelong and lifetime engineering education practice, as well as identify potential solutions. Some of the challenges include:
   – consistent requirements that are more globally accepted; and
   – funding mechanisms across the globe for continued engineering education rather than pockets of corporate or governmental support.
3. *The following ideas could be potential tools in future solutions*:
   – Blockchain credential storage
   – An engineering card similar to FEANI
   – New business and pedagogical models for lifetime education

Create global polices and associated scorecard(s)

Global policies for sharing and recognizing CEE learning can be accomplished through conversations, proposals and the adoption of processes. The development of a scorecard(s) is envisioned to assist with tracking the progress of goals and recommendations from the group. The scorecard(s) will provide both content and context for the recommendations, making sure that all parts of the international workforce are included in the reflection and action.

Conclusion

The coupling of new methods for formal engineering education at the traditional undergraduate and graduate levels with the methodologies described in this chapter will produce globally competent engineers. Neither activity by itself is sufficient in today's complex and fast-changing world. The inclusion of learning that takes place on the job via NFIF learning activities is warranted so that the focus on constant learning, reflection and the credibility of information learned can be part of the

everyday life of an engineer or engineering technician, enabling the full realization of the SDGs at the global level. UNESCO's leadership, in partnership with many other organizations, should enable the continual re-education and retooling of tomorrow's workforce.

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