GEDC INDUSTRY FORUM
Concept Paper

University-Industry Collaboration to Develop the Engineer of the Future

Produced for the GEDC Industry Forum,
Fontainebleau, France, 28-30 June 2017

Written by Monica Collins of Petrus Communications

GEDC INDUSTRY FORUM CONCEPT PAPER: UNIVERSITY-INDUSTRY COLLABORATION TO DEVELOP THE ENGINEER OF THE FUTURE

Contents

I. Introduction

That the world we live in is in changing, towards a more global one of increasing complexity, is not a new concept. Experts have been discussing it for decades, and these discussions multiplied after the end of the 1980s, when the pace and impact of globalisation increased. And due to the concomitant shift of the global economy towards a knowledge-based one, thanks in a large part to the proliferation of information and communication technologies, engineers have been at the centre of the discussions on globalisation and what impact it might have on the field of engineering and engineering education.

For example, in 1991 I. Arango wrote about how competition among nations in a global economy would increase the importance of engineering education in making new engineers more capable of competing and collaborating with foreign counterparts.[1] Also in 1991, authors Moran and Richard argued that the global economy was "here to stay" and asked the questions "What skills do technical professionals require to meet its demands? How must they interact across cultures to be effective? How can their needs be developed?"[2] These are questions still being asked today, in a world still concerned with globalisation, but also concerned with many other new trends as well.

II. In Transition – The Trends of Today[3]

Globalisation continues today, but is joined by another broad trend – **digitalisation** – which has resulted in the blurring of boundaries "between nations, disciplines, and professions, between academia and industry, and between applied science and engineering."[4] In a world where everyone and everything is networked and connected, distance, time, and space are no longer barriers to innovation, or to engineering.[5]

Part of the digitalisation trend, the Internet of Things (IoT), Big Data, and Virtual and Augmented Reality are playing an increasingly larger role in society and the development of products and enterprises. This presents enormous opportunities for engineers, but also many challenges, especially those of cyber and data security, and the need to be able to "operate at the interface between the human physical (the constructed) and the virtual worlds."[6]

Due in a large part to globalisation and digitalisation, another important trend is underway, what author A. Kamp calls the **horizontalisation of the socio-economic world**.[7] With information and knowledge spread more and ever more rapidly and openly today, traditional hierarchies have been flattened. This can be seen in the transfer of power to the end-user or consumer, who has extremely broad access to information about products, services, pricing, etc.; in the "open innovation" movement that moves innovation from an "in-house" activity to one relying on multiple sources; and in the rise of non-university producers of knowledge and providers of education.

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[1] Arango (1991).
[2] Moran & Richard (1991). Quotes from abstract.
[3] This section owes a great debt to A. Kamp's (2016) skillful description of current global trends.
[4] Kamp (2016), p. 12
[5] *Ibid*.
[6] Andrew Hogg – Director of Education at Total, personal communication, 14 June 2017
[7] Kamp (2016), p. 14

All of the above has resulted in a **blending of technical, economic, and societal structures**. Innovation and business are increasingly driven by clients and consumers rather than technology, leading for example to the rise of design thinking in engineering which is centred around the end-user. Growing access to information, know-how, and inexpensive and user-friendly software, tools, and materials, means that it is now easier for nearly anyone to design, develop, manufacture, finance, and sell products.[8] For example, a product 3D-printed in an individual's basement now has the potential to disrupt markets that were previously considered to be impenetrable.

III. Responses – Industry and Engineering Education[9]

As the world rapidly changes, so does industry and its needs. This has led to many companies being unable to find the talent that they need, when they need it, and this is particularly true for companies that employ engineers. According to a global survey of employers performed by Manpower Group in 2016 – engineers and technicians are number 4 and 5 respectively on the global list of most difficult positions to fill.[10] These talent shortages are an issue that has led companies to explore in great depth the skills they need in engineers, and then reach out to engineering educators to try to resolve these shortages.

Desired Attributes of an Engineer – The Beginning

One of the first companies to do this was **Boeing**, which published a list of "Desired Attributes of an Engineer," for engineers in a new globalised world in the early 1990s.[11] The list was created in order to "establish a basis for an on-going dialogue with academe" and was meant to include only "durable foundational skills" that would prepare any modern engineer for the professional world, no matter how the world changed. Included in this list of desired attributes was:

- **A good understanding of engineering science fundamentals** (mathematics (including statistics), physical & life sciences, information technology (far more than just "computer literacy"))
- **A good understanding of design and manufacturing processes** (i.e., understands engineering)
- **A multi-disciplinary, systems perspective**
- **A basic understanding of the context in which engineering is practiced** (economics (including business practice), history, the environment, customer & societal needs)
- **Good communication skills** (written, oral, graphic, listening)
- **High ethical standards**
- **An ability to think both critically and creatively – independently and cooperatively**
- **Flexibility. The ability and self-confidence to adapt to rapid or major change**
- **Curiosity and a desire to learn for life**
- **A profound understanding of the importance of teamwork.**[12]

Discussions and debates on engineering education, and how industry and universities can work together to develop engineers with the proper skills, increased after this publication and have remained important, principally in the U.S. and Western Europe in the beginning and now in numerous regions. Various companies, universities, engineering education organisations, international organisations, accreditation organisations, etc. have assembled experts to work on compiling, reviewing, revising, and adding details to lists of attributes, skills, and competencies desired in current and future engineering graduates – many of them based on Boeing's list.

[8] *Ibid*.
[9] The publications reviewed in this section come almost entirely from North American and Western European organisations and companies. This is not due to intentional bias, but rather to a lack of literature found from other regions during desk research.
[10] Manpower Group (2016)
[11] McMasters & Komerath (2005)
[12] *Ibid*., p. 3

Accreditation Organisations

One accreditation organisation, the U.S.-based **Accreditation Board for Engineering and Technology (ABET)**, used the Boeing list as one of its basic three source documents for the student learning outcomes section of its new ABET EC 2000 accreditation rules, which were approved in 1996 and were meant to "encourage rather than hinder educational experimentation."[13] The list of eleven student learning outcomes is still used today, and while quite similar to the Boeing list, adds to or reformulates some of the items as can be seen in the following criteria: **an ability to identify, formulate, and solve engineering problems; a knowledge of contemporary issues; and an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice**.[14]

Other accreditation organisations, such as the **Canadian Engineering Accreditation Board (CEAB)**, also base their accreditation criteria on those listed in the **Washington Accord** document, which states that its list of criteria is meant to be a guide for signatories and others to develop outcomes-based accreditation criteria.[15] The Washington Accord's criteria is organised into three separate categories: a graduate attributes profile, a knowledge profile, and a definition of the level of problem solving. The list of graduate attributes is similar to those of Boeing and ABET, except that it goes much further into detail when defining items, and it also includes **project finance and management**.[16]

Projecting the Future of Engineering

Projecting what the mid-term future would look like, and recommending skills and attributes for future engineers based on their projections, has been the focus of some organisations. For example, the **U.S. National Academy of Engineering (NAE)**, which published its "The Engineer of 2020: Visions of Engineering in the New Century" in 2004. In the paper, technological and societal, geopolitical, and professional changes are explored and then the attributes of future engineers who will be working on the challenges presented by the changes covered. These include attributes such as **strong analytical skills**, **creativity**, **ingenuity**, **professionalism**, and **leadership**.[17] While the technological landscape today is different than what it was in 2004, the NAE's projections have largely proven to be correct, and have inspired other organisations working on the topic of skills for the engineer of the future.

Global and Industry Focussed

In its project paper for its Attributes of a Global Engineer Project (2008 – 2015), the **American Society for Engineering Education (ASEE)** mentions the NAE publication among others which informed an initial list of attributes for global engineers, which was later narrowed down significantly following a survey, and work done in focus groups and workshops. The goal of the ASEE project was to identify and validate specific knowledge, skills, abilities, and perspectives that would be required of an engineer living and working in an increasingly global context. It eventually produced a list of 20 attributes, organised into five categories of attributes: **technical**, **professional**, **personal**, **interpersonal**, and **cross-cultural**.[18] Each category then contains a number of specific attributes, most of which are identical to or elaborate on those of the publications mentioned above, except for a few: **fluency in at least two languages**, **maintains a positive self-image and possesses positive self-confidence**, and **mentors or helps others accomplish goals**.

Both the ASEE Global Engineer Project, and its project commissioned by the **U.S. National Science Foundation (NSF)** entitled **Transforming Undergraduate Education in Engineering (TUEE)**, have placed an emphasis on collaborating with and receiving input from industry while compiling their lists. For example, at the TUEE workshop that compiled a set of needed and desired knowledge, skills, and attributes (KSAs) in engineers, nearly 75% of participants involved were industry representatives.[19] 15 KSAs were identified as high priority by workshop attendees. These high priority KSAs are similar to what above organisations have published, with the exception of: **self-drive and motivation**, **willingness to take calculated risks**, and **entrepreneurship and intrapreneurship**.[20]

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[13] *Ibid*., p. 3
[14] ABET (2006), ABET (2015)
[15] CEAB (2014), IEA (n.d.)
[16] IEA (n.d.), p. 16
[17] NAE (2004)
[18] ASEE (n.d.)
[19] TUEE (2013)
[20] TUEE (2013) pp. 11-12

Development Focussed

Most of the publications by companies and organisations on needed and desirable skills, competencies, and attributes of current and future engineering graduates have come from North America and Western Europe, and do not take into account the perspectives of other countries and regions the majority of the time. One of the few that does is the **United Nations Educational, Scientific and Cultural Organization (UNESCO)** publication entitled Engineering: Issues Challenges and Opportunities for Development. The publication addresses the role of engineering in development, and how engineers can address challenges and issues such as climate change, urbanisation, poverty reduction, and sustainable social and economic development. Talent gaps in engineering in developing countries are in some cases enormous, which can have devastating consequences. The skills, competencies, and attributes listed in the publication are essentially the same as those above, with the main difference being a heavy emphasis on **awareness and sensitivity to development issues**, and **sustainability**.

In addition to the development issues raised in UNESCO's publication, experts have pointed out that along with the benefits of globalisation have come many negative impacts, which have resulted in displacement and social unrest. Future engineers should therefore, be trained to **think about both those who lose out due to globalisation as well as those who gain, and be able to propose mitigation**.[21]

[21] Andrew Hogg – Director of Education at Total, personal communication, 14 June 2017

IV. Consolidated List of Skills and Competencies

Literature reviewed above, along with several other publications not mentioned, have been used to create a consolidated list of skills and competencies. This list uses as its foundation Boeing's list of Desired Attributes of an Engineer and then adds to it and modifies it following the literature above. It is out of necessity not all-inclusive, but covers the most recurrent skills and competencies, as well as some that may not be mentioned often, but are important.

The purpose of this list is to serve as a reference to GEDC Industry Forum participants on desirable skills and competencies in engineering graduates supported by broad consensus.

Three categories of skills and competencies can be seen below. The first two, Transversal Engineering Skills/Competencies and Soft and Professional Skills/Competencies, contain skills and competencies that are global in nature, i.e. they will always be important regardless of projected future changes in the world, even if they might shift in relative importance. The third category, Current High Demand Skills/Competencies cover those that are behind a large part of current talent shortages.

Skills and Attributes taken directly or adapted from the original Boeing list are in bold.

Transversal Engineering Skills/Competencies

- **Engineering Science (mathematics, physical and life sciences, information technology)**
- **Proficiency in design and manufacturing processes**
- **Multi-disciplinary, systems perspective**
- Profound **understanding of the context within which engineering is practised (business, economics, environment, customer and societal needs)**
- Problem identification, analysis, and solving

Soft and Professional Skills/Competencies

- **Effective communication (written, verbal, graphic, electronic)** with both technical and non-technical audiences
- **High ethical standards** and behaviour
- **Critical and creative thinking, independently and cooperatively**
- Resilience – **the ability and self-confidence to adapt to rapid or major change**
- **Desire and willingness to learn (lifelong learning)**
- **Teamwork**
- Commercial awareness
- Entrepreneurship
- Global and cultural awareness and sensitivity
- Awareness of and sensitivity to development issues

Current High Demand Skills/Competencies

- Design thinking
- Data science/digital skills
- Cybersecurity
- Artificial Intelligence
- Sustainability

V. For Further Discussion: The 'Who' and 'How' of Developing Skills and Competencies

Given the broad consensus on what skills and competencies are needed in future engineers, the critical next step in the context of the GEDC Industry Forum to ensure engineering graduates have these skills is to answer the following questions:

1. Of the stakeholders involved, who is best suited to ensure the development of each of the necessary attributes, skills, and competencies in future engineers?

Stakeholders include primary and secondary education providers, universities (management, faculty/department heads, heads of career and employability services, professors), employers, employees, students (not limited only to those enrolled in institutions of higher education), government (policy makers, funding bodies), professional associations, and alumni. [22]

Alternatives to universities such as community colleges, vocational schools, apprenticeship programmes, private education providers, etc. are not always included in discussions about developing attributes, skills, and competencies in graduates but are also influential stakeholders especially during a period of transition in higher education. This transition is due to the rapid pace of the trends mentioned in Section II and the resulting talent shortages, in addition to challenging economic conditions and results in, among other things:

- **lifelong learning** becoming increasingly necessary to keep up with the pace of technological change, and
- **employability** becoming much more important to students and employers.[23]

This means that it is ever more imperative that learning does not stop when students graduate, and has resulted in the **shifting of traditional roles** of universities, employers, and students – the three groups of particular interest at the GEDC Industry Forum. For example, universities are now presenting students with alternatives to traditional degree programmes (online courses, competency-based programmes, etc.). Employers are increasingly training existing employees – Manpower Group found in their 2016 Talent Shortage Survey that the number of employers providing training and development programmes to employees has doubled since 2007 to 53% in 2016.[24] Students, in the broad sense as individual learners, are going outside the traditional university system and learning on their own thanks to the wealth of information and knowledge available online for free or at low cost.

Arguments have been made that certain attributes, skills, and competencies required of future engineers are better developed by either universities, employers, or students themselves – for example universities developing in students the desire and ability to learn how to learn, and employers developing professional skills. The overall consensus however is that stakeholders need to be aware of each other's changing roles, and that ultimately no one stakeholder can be completely responsible for skill development. Therefore, **collaboration is vital**.

2. Given that collaboration is key, how can universities, employers, and students best work together to develop the necessary attributes, skills, and competencies in future engineers?

Good examples exist of initiatives that bring together universities, employers, and students in order to develop necessary attributes, skills, and competencies. For instance, student design competitions at McMaster University in Canada, which are one of the over 20 activities that make up the McMaster Faculty of Engineering Experiential Learning Ecosystem.[25] The competitions, such as the DeltaHacks hackathon, include collaboration with industry through industry partners' provision of challenges/problems for students to work on, industry representatives acting as mentors and judges, etc.[26]

An example of an employer-led initiative is the Airbus Fly Your Ideas student competition which gives teams of students from around the world the opportunity to put what they've learned in the classroom to the test by

[22] See Blackmore et al. (2016) for information on how alumni networks are utilized by institutions of higher education to help develop employability skills in students. For a discussion on government's role in ensuring the development of skills in individuals, see Deloitte University Press (2014).

[23] See "Special Report: Lifelong Learning" (2017) for a discussion on the trend towards lifelong learning, and Blackmore et al. (2016) for more information on the increasing focus on employability.

[24] Manpower Group (2016)

[25] McMaster Faculty of Engineering Experiential Learning Asset Map (2017)

[26] See http://deltahacks.com/ for more information on DeltaHacks

working on real life challenges in the aviation industry. Over the course of the competition, students work with their teams and assigned Airbus Mentor and Airbus Expert, who help them develop their projects.

By working in teams on real world challenges with the support of industry and university partners, students who participate in initiatives such as the above have multiple beneficial learning outcomes, including:

- Teamwork and leadership skills
- Project management
- Communicating and presenting complex ideas
- Resiliency – for example adapting after receiving critical feedback
- Deepen and apply technical knowledge
- Learn and apply industry standards

One area in which collaboration is key but not particularly well-developed today is in the **communication and coordination of definitions of skills and competencies** between universities, employers, and students. When employers say that they would like more graduates with leadership skills, for example, the employer's idea of leadership skills may be quite different from that of those who develop leadership training programmes at universities. This can cause issues when attempting to ameliorate talent shortages, and when trying to accurately measure the success of initiatives.

In conclusion, while there are many good examples of collaboration between universities, employers, and students, there are **still issues that need to be addressed and room for innovation** to ensure that collaboration best develops the attributes, skills, and competencies necessary for engineers in the 21st century.

The conclusions of this concept paper therefore represent the starting point for discussions at the GEDC Industry Forum.

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Thank you to all of the GEDC Industry Forum Working Group members who contributed to this paper.

For questions about the Concept Paper, please contact:

Monica Collins

Research Consultant, Petrus Communications

monica@petruscommunications.com

+33 (0) 671 003 949

For questions about the GEDC Industry Forum, please contact:

Kirsten Williamson

Founder and CEO, Petrus Communications

kirsten@petruscommunications.com

+33 (0) 673 501 372