Re-inventing Engineering Curriculum

Rao Bhamidimarri

Abstract The strengths and weaknesses of the traditional engineering education in the context of today's industry needs has been a focus of the professional institutions and learned societies over the last decade. The need to broaden the engineering curriculum to equip engineering graduates with skills and attributes for them to succeed professionally, to foster creativity and innovation and to thrive in a multi-disciplinary context is recognised. The role of engineers in revitalising national economies has also been discussed widely. This paper captures the results of research undertaken with support from industry. A conceptual model for engineering curriculum is proposed incorporating design thinking and business skills. The undergraduate engineering curriculum at London South Bank University was redeveloped based on these concepts. The curriculum philosophy is discussed and the implementation of the redesigned curriculum is reported.

Keywords Curriculum innovation · Skills · Graduate attributes · Conceptual model · Design thinking

1 Introduction

The challenges of this century are profound and wide ranging. Health and well-being, water, energy and food are the foci as the population approaches 9 billion. This will require creative and innovative engineers, who can not only set the agenda for the industry of the future, but also have the leadership and business skills for implementation. Thus the primary mission of the 21st century engineer requires redefining, embracing sustainable development.

Engineering profession has traditionally focused on technical and professional knowledge, and skills for decades, contributing to a step change in wealth creation

---

R. Bhamidimarri (✉)
London South Bank University, 103, Borough Road, London SE1 0AA, UK
e-mail: bhamidir@lsbu.ac.uk

R. Bhamidimarri and A. Liu (eds.), *Engineering and Enterprise*,
DOI 10.1007/978-3-319-27825-4_4

and improved standard of living across the world. These improvements have been primarily achieved through the mission of harnessing the powers of nature for the benefit of mankind. However, as the global grand challenges of sustainability, climate change and resource depletion are better articulated, the non-technical factors; social, environmental and ethical; are increasingly recognised to be integral to the engineering profession. At the same time, in a competitive economy, the business context is vital. In today's globalised market place, the career success of engineering graduates and that of their employers demands that the graduates are also creative and innovative. Thus, engineering education can no longer continue to be limited to the study of engineering science, measurement, modelling and synthesis of these.

The potential challenges faced by the US were discussed in the report by the National Academies (2005), which identified a way forward for increasing the quality and numbers of science and engineering graduates for the US to retain its leadership in the global economy. In the UK, the Royal Academy of Engineering articulated the areas for development in engineering education through their reports, Educating Engineers for the 21st Century (2007) and Engineering Graduates for Industry (2010). The Confederation of British Industry (CBI) identified not only a serious shortfall in the numbers of engineers required by the UK industry, but also pointed to the gaps in graduate attributes sought by the employers (2012). The skill gaps identified in these reports vary from basic functional skills such as literacy, numeracy, communication and team working to higher level skills including research and analytical abilities.

There have been various initiatives in engineering colleges in the US, UK, Australia and some European countries to address the skills gaps. One such example is the iFoundry at University of Illinois at Urbana-Champaign (www.ifoundry.illinois.edu), which offers courses in business and leadership for engineering students as well as an innovation certificate. Olin College received the first group of students in 2002 and developed a novel engineering programme in partnership with the students (Goldberg and Somerville, 2014). Many other engineering institutions introduced modules in business and entrepreneurship either as part of the engineering curriculum or in addition to the core curriculum.

2 Leadership and Management in Engineering Industry

The engineering and technology companies were established and led by scientists and engineers until the middle of 20th century. This is because engineers have a practical and pragmatic orientation, analytical problem solvers and architectural thinkers. With the growth of business schools over the last five decades, however, the top roles have been increasingly filled by people with finance and commerce education, although there are increasing numbers of companies hiring engineers as CEOs in recent years. Aquino reported (2011) that 33 % of the S&P 500 CEOs had engineering education. A recent survey by Harvard Business Review (2014) reported that 10 out of the 50 best performing companies have an engineering education.

The perception that engineers are technical “geeks” with limited social and business skills continues to hinder the career progression towards the leadership roles. The traditional engineering curricula provided limited or no opportunities for the development of leadership, people and financial management, communication and other “soft” skills, whilst equipping the graduates with strong analytical and problem solving abilities. In view of the emphasis on technical content, undergraduate engineering curriculum offered limited opportunities for fostering creativity and innovation. These limitations are increasingly being recognised the educational institutions, employers and the professional engineering institutions.

An analysis by this author of the leadership of the engineering and technology firms in New Zealand in revealed that 7 out of 10 engineering and technology companies were headed by individuals from professions other than engineering and technology. The CEOs were typically from finance professions. Further investigation revealed that the industry leaders, who were educated as engineers, invariably had further education and training in management or entered their family businesses following graduation as engineers.

Over the last three decades, Silicon Valley provided an environment for technology start-ups led by engineers to develop into high technology multi-national companies. Many of these CEOs subsequently moved to head up other companies. Several of the engineers who moved into leadership roles typically supplemented the engineering education with an added MBA or executive management education. However, the bolted on management education has not always proved successful as this approach does not bridge all the identified gaps and not all engineers who pursued this option have succeeded in translating the business management knowledge into engineering context.

3 What the Employers Want

In order to assess the engineering graduate attributes sought by the employers, 320 business and industry leaders were approached. The people approached occupied chief executives, presidents, directors, vice-presidents and managing directors. A simple questionnaire was designed to gauge the employer expectations of current and future engineering graduates. 71 completed questionnaires were returned representing 22 % response rate. The survey tried to consider inherent and learnt, technical and non-technical attributes. This was followed by one to one interviews with 30 selected respondents representing the entire spectrum of the engineering businesses in terms of scale of operation, turn over and profitability.

Of the companies that responded, over 50 % employed 200 or more people with 13 % employing less than 20 people. 38 % of the responding companies have an annual turnover of over £10m with some over a billion pounds, with an additional 21 % of companies having an annual turnover between £2m and £10m. The businesses of the respondents ranged from chemical manufacture to aerospace and defence, from construction and consultancy to product innovation and design, and from low cost manufacturing to high value added products.

73 % of respondents held the positions of Chairman, Vice-President, Chief Executive, Regional and Group Directors. The rest of 19 questionnaires were completed by people holding positions ranging from Business Development Director to Personnel Director.

Maximising profits was the primary business objective for 42 % of the respondents, while 28 and 22 % identified increasing market share and technological innovation respectively as their second priority.

The following personal skills and attributes that were seen as particularly important (Fig. 1):

- Communication skills
- Commitment
- Motivation
- Confidence

Being responsive to change and having the ability to thrive in a challenging environment were also noted as important as self-confidence (Fig. 2).

The preferred business skills were identified as commercial awareness, financial and people management, and sales and understanding market awareness skills. Of the technical and professional competencies problem analysis, critical evaluation, project development and delivery, and the application of the engineering techniques and tools were preferred.

It is interesting to note that only one respondent identified risk taking as an important attribute while work experience was seen as important in employing engineering graduates. This may be because the questionnaire and the interviews focused primarily on employers views on fresh engineering graduates entering the companies.

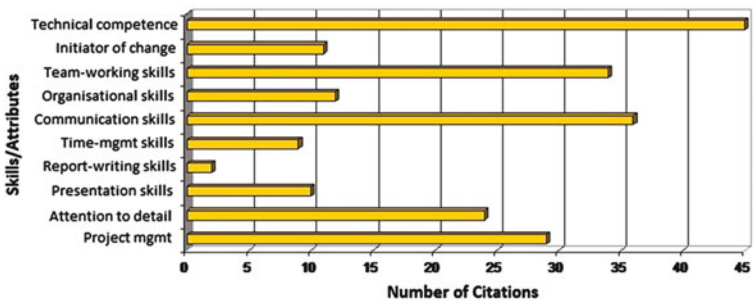


Fig. 1 Skills and attributes the employers expect the engineering graduates to learn through the programme of study

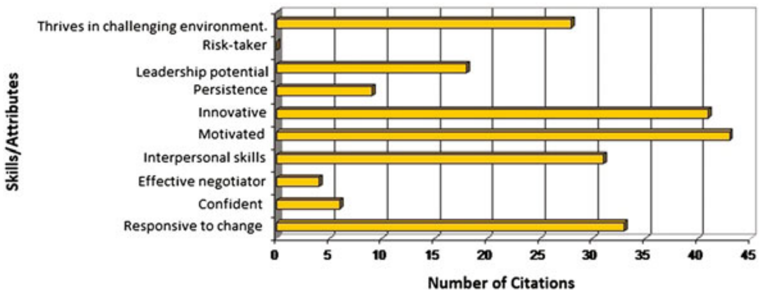


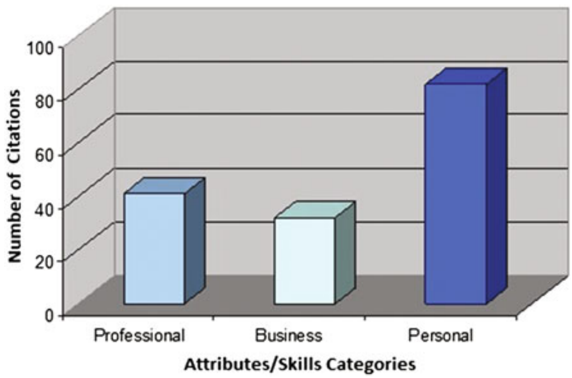
Fig. 2 Generic and inherent skills and attributes sought by employers

4 A New Approach to Engineering Education

The research programme considered the inputs from the industry leaders and the published information on the qualifications of the CEOs of engineering businesses as well as the career progress of engineering graduates. Extensive cross analysis of the feedback from the questionnaires and interviews was carried out. Published information on the CEO's educational background and the company performance was also considered. Curriculum innovations being mooted in engineering schools internationally were reviewed and visits several of the engineering schools were undertaken. The survey revealed that the personal attributes of the graduate engineers were seen as more important compared to professional and business competencies (Fig. 3).

Based on this research, a multi-disciplinary approach to engineering curriculum is proposed in this study.

Fig. 3 Key qualities the employers feel the current engineering graduates lacking



5 Curriculum Philosophy

The research conducted into entrepreneurship education revealed that over half of the higher education institutions in the UK offer courses in entrepreneurship primarily in the context of business education. An estimated 10 % of all students in higher education undertake elements of entrepreneurship in their programmes. Vehicles to promote entrepreneurship education have been developed. An example, the Scottish Institute for Enterprise promotes programmes such as the student intern programme, a social enterprise challenge, an international enterprise summer school and master classes in entrepreneurship for students in higher and further education. While these programmes have brought entrepreneurship into focus in higher education, they remain business education rooted and are commonly bolted on to the core discipline based curricula.

Focus on creativity and entrepreneurship in most undergraduate engineering programmes however, has not developed beyond optional modules being made available to students. There are several universities offering postgraduate programmes with an entrepreneurship focus. The Hunter Centre for Entrepreneurship at the University of Strathclyde makes several undergraduate and postgraduate modules available to engineering students. A number of other institutions including Nottingham, Sheffield, Warwick, Imperial and UCL also courses that the students can choose to opt to study alongside their primary discipline based programmes. London South Bank University offers a customised postgraduate programme in enterprise.

Internationally, Germany has had established programmes for several decades in "economic engineering", which attempted to integrate business and engineering. More recently, MIT and Stanford have led the development of programmes that attempt to integrate engineering and entrepreneurship at postgraduate level. The enterprise focus in engineering education also has emerged in several other US universities such as Lehigh, Maryland and North Carolina. The Republic of Singapore has invested substantially during in the last decade in innovation and enterprise leading to enterprise focussed academic activities, particularly in engineering and technology at National University of Singapore and Nanyang Technological University through additional modules and seminars on entrepreneurship.

However, it is increasingly recognised that optional modules in the undergraduate engineering curriculum are unlikely to foster the attributes thought to reflect entrepreneurial activity.

In 2002, with a substantial gift from the Frank Olin Foundation in the USA a specialised engineering college was opened to offer an engineering curriculum that takes into account the attributes increasingly sought by the employers in new engineering graduates. This is an example where attempts are being made to integrate undergraduate engineering curriculum with design, communication, business and entrepreneurship studies. While the curriculum at Olin incorporates the elements of active, project based learning and interaction with industry, much of the learning remains elective-based. Subsequently, several other universities and colleges such as Georgia Tech and Greenfield Coalition of colleges and universities initiated activities to introduce entrepreneurship in undergraduate education.

6 An Innovative Engineering Curriculum

The primary objective of redesigning the undergraduate engineering curriculum is to facilitate the development of future engineering leaders, who not only have a thorough knowledge of engineering analysis and design principles, tools and techniques, and synthesis of elements of relevant knowledge but also have gained an appreciation of business, social and environmental contexts of engineering. The ethos of life-long learning is to underpin the education process in order for the graduates to capitalise on the emerging opportunities in a rapidly changing technical and global environment.

6.1 Cornerstones of the Curriculum

- **Design** thinking will play a key role in the development of engineers to be creative product innovators and problem solvers. This plays a key role developing skills to integrate technical and non-technical knowledge through the study of design processes and contextual issues. This is achieved through specialist and embedded design studies throughout the programme.
- **Engineering** discipline studies will focus on principles of engineering science, engineering mathematics and integrative technology studies and will develop analysis, measurement and modelling, synthesis and problem solving skills.
- **Business and enterprise** studies will focus on the study of the principles and tools in finance and business management in order to develop commercial awareness. Ability to identify opportunities and create value added products and services will be achieved through the study of real time case studies and modules on entrepreneurship and enterprise development.

The author developed a conceptual model bringing together the key curriculum components of knowledge to foster innovation in engineering education. This is shown in Fig. 4 and depicts the contribution of each of the component to an integrated programme that equips engineering graduates to operate effectively. The programme of study developed and implemented based on these principles not only equips the graduates technically and professionally, but also prepares them with creative abilities and business acumen. The graduates with the relevant multi-disciplinary education with a strong self-directed learning are likely to be better placed to progress into management and leadership roles in the modern engineering business environment.

7 Implementation at London South Bank University

The author led a fundamental review of the engineering curriculum at London South Bank University in 2012 and redeveloped the curriculum based on the model shown in Fig. 4. A key objective of the curriculum change was to transform the curriculum to one that is student-led. The industry is rapidly embracing digital technologies and ability to think, design and innovate in a virtual environment is increasingly important. Therefore an integrated virtual engineering environment including digital design and prototyping facilities was developed and established to enable all engineering students to gain experience in designing and operating in a virtual environment.

Two new substantive modules were introduced and these are (1) Design and Practice, and (2) Innovation and Enterprise for students in all engineering programmes.

1. **Design and Practice**:
   This module requiring 330 h of student learning focuses on creative thinking and problem solving techniques including mind mapping and brainstorming; conceptual design and synthesis. These techniques are linked to practical work ranging from experimental design, undertaking investigations, analysis and interpretation of results progressing to prototyping and model building. Organisation, team working, oral and written communications and presentations are also learnt through this module.

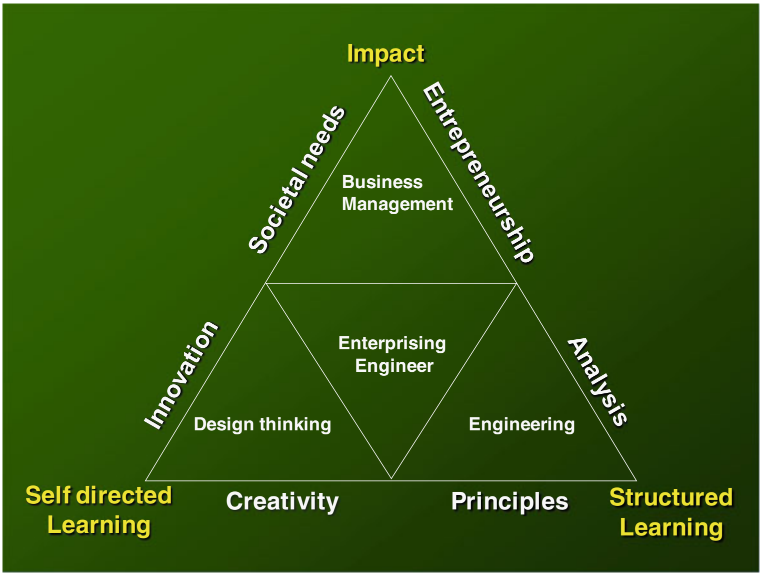


Fig. 4 Curriculum structure for fostering enterprise in engineering education. © R. Bhamidimarri, 2014

2. **Innovation and Enterprise**:
   In this module requiring 150 h of student learning, the students study innovation and enterprise processes for development of ideas into financially viable and profitable businesses, including opportunity specification, market research and testing, design methods and processes, project and operations management and financial evaluation. Development of a business plan and a business strategy, innovation and intellectual property management are also studies as part of this module.

I addition to these mandatory modules, the study of project management is introduced across a range of courses.

The distinctive feature of the curriculum is reflected not just by the content but the way the curriculum is implemented. The personal attributes and "soft skills" that the industry leaders identified to be lacking in the current engineering graduates are embedded through the learning and teaching and assessment methodologies across the curriculum.

Acknowledgements The author acknowledges his many discussions with Professor Rolf Cremer at Massey University, which inspired him to undertake this work and the support of Edinburgh Napier University in conducting employer survey. James Barnham and Chris Dowlen coordinated the development and implementation of the modules on Design and Practice, and Innovation and Enterprise at London South Bank University respectively. Tony Roberts and Federico Rossi led the project development and implementation of virtual engineering and digital design facilities. The author thanks all the engineering staff at London South Bank University for embracing the step change to engineering education and making the innovative engineering education a reality.

References

Aquino J. Business Insider. March, 2011

Educating Engineers for the 21st Century (2007) The Royal Academy of Engineering, London, UK

Engineering Graduates for Industry (2010) The Royal Academy of Engineering

Goldberg DE, Somerville M (2014) A whole new engineer. Three Joy Associates Inc., USA

Harvard Business Review, November 2014

Learning to grow: what the employers need from education and skills (2012) Educations and Skills Group, CBI, London

Rising above the gathering storm: energising and employing America for a brighter economic future (2005) National Academy Press, USA