ENGINEERING CURRICULA IN THE 21ST CENTURY: THE GLOBAL SCENARIO AND CHALLENGES FOR INDIA

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Abstract

In the 21st century's global economy, the new challenges facing the engineering profession have arrived, confirming the need to restructure engineering curricula, teaching and learning practices, and processes, including assessment. Possessing merely technical knowledge no longer guarantees an engineering graduate a successful career. And while all countries are facing this dilemma, India is struggling the most. It has been argued that most Indian engineering educational institutions struggle with the systemic problem of centralisation coupled with an archaic examination system that is detrimental to student learning. This article examines some internationally renowned educational institutions that are embracing the growing importance of non-technical subjects and soft skills in 21st century engineering curricula. It will then examine the problems that India faces in doing the same.

Index terms: curriculum, 21st century, India, engineering education.

INTRODUCTION

The 21st century has arrived, bringing with it new social, economic and environmental challenges. The world has become a global village; concern for sustainable environments has increased; and engineering projects cross national borders, with engineers working in multicultural teams, with different languages and nationalities. The new challenge for engineering is how to produce goods and services, and develop infrastructure, without damaging the environment. 'Carbon footprint' is the new buzzword in any engineering project. In the last century, engineering projects had three main constraints: humans, material and money. However, in the new century, products and services must be not only economically viable but environmentally sustainable, as well as ethically and socially appropriate. Engineering education needs a new paradigm if it is going to successfully train future engineers to fulfil society's new demands.

THE CHANGING NATURE OF THE ENGINEERING PROFESSION

Engineering as a profession is directed towards applying and advancing skills that are based on a body of distinctive knowledge that includes mathematics, science and technology integrated with business and management, which is acquired through education and professional growth in an engineering discipline. Ultimately, engineering is involved with developing and providing infrastructure, goods and services for industry and the community [1].

A study by J. P. Trevelyan [2] at the University of Western Australia recently revealed that technical coordination has become the most prominent aspect of engineering practice in the real world. 'Technical' knowledge of a discipline is no longer enough to enable an engineer to solve to complex, interdisciplinary problems.

Similarly, a review committee appointed by the National Academy of Engineering in the United States argues that graduates must now consider economic, political, ethical and social constraints to be boundary conditions that define the possible range of solutions for future engineering problems [3]. Engineering projects now have subassemblies or parts from different parts of the world (see Figure 1). These projects are executed by teams whose members come from different countries, speak different languages and share different cultures. The success of such global projects depends on not only technical skills but high-order soft skills, such as communication and teamwork.

Recently, issues such as environmental degradation, global warming and sustainability have become as crucial to engineers as fundamental engineering-design criteria such as strength or buckling. Sustainability has (or will soon) become an integral part of 21st century engineering practice. Consequently, topics relating to environmental regulations, policies and standards, and sustainable approaches in design, manufacturing and services, must be incorporated into engineering curricula to prepare engineering graduates for the global challenges ahead.

The Institution of Engineers, Australia, visualised these challenges and suggested that:

Engineering education must become more outward looking and more attuned to the real concerns and communities. Courses should promote environmental, economic global awareness, problem solving ability, engagement with information technology, self-directed learning and lifelong learning communication, management and teamwork skills, but on a sound base of Mathematics and engineering technology. For engineering graduates to take a more effective societal role they must be better communicators. This means that, in addition to having the ability to explain technical problems, they must be politically and socially aware so that technical decisions can be made, understood and communicated with sensitivity, especially across cultural boundaries [4].

The aforementioned 21st century challenges have placed overwhelming pressure on curriculum designers to incorporate subjects relating to humanities, social sciences,
environment and ecology, management, languages and professional communication into engineering curricula. Furthermore, integrating technology into the development of public infrastructure and people's lives will demand more extensive and broadbased knowledge than technical knowledge alone can provide.

Professional bodies, industries, universities and governments across the globe recognise the new and complex challenges ahead. They support and even drive the thrust to update engineering curricula to prepare students for these challenges. This is reflected in the revised lists of engineering attributes developed by both Engineers Australia and the Accreditation Board for Engineering and Technology in the United States, which are described in the following section.

Approximately 70 per cent of parts are from outside suppliers, demonstrating the globalisation of engineering enterprise [5].

Reforms in engineering curricula in Australia and the United States

Accreditation of engineering curricula in Australia

In Australia, a professional engineer must have an accredited degree. Engineers Australia, a non-government professional body, grants this accreditation. Engineers Australia uses the following basic criteria to accredit engineering programs:

**PE1 KNOWLEDGE BASE**

PE1.1 Knowledge of science and engineering fundamentals

PE1.2 In-depth technical competence in at least one engineering discipline

PE1.3 Techniques and resources

PE1.4 General knowledge: Broad educational background and/or general knowledge necessary to understand the place of engineering in society

**PE2 ENGINEERING ABILITY**

PE2.2 Understanding of social, cultural, global, and environmental responsibilities and the need to employ principles of sustainable development.

**PE2.3** Ability to utilise a systems approach to complex problems and to design and operational performance.

**PE2.4** Proficiency in engineering design.

**PE2.5** Ability to conduct an engineering project.

**PE2.6** Understanding of the business environment.

**PE3 PROFESSIONAL ATTRIBUTES**

**PE3.1** Ability to communicate effectively, with the engineering team and with the community at large.

**PE3.2** Ability to manage information and documentation.

**PE3.3** Capacity for creativity and innovation.

**PE3.4** Understanding of professional and ethical responsibilities, and commitment to them.

**PE3.5** Ability to function effectively as an individual and in multidisciplinary and multicultural teams, as a team leader or manager as well as an effective team member.

**PE3.6** Capacity for lifelong learning and professional development.

**PE3.7** Professional Attitudes. [6]

Accreditation criteria of engineering curricula in the United States

In the United States, the relevant accreditation agency is the Accreditation Board for Engineering and Technology (ABET). All engineering degree curricula are designed to produce engineering graduates who demonstrate the following accreditation requirements:

a) an ability to apply knowledge of mathematics, science, and engineering

b) an ability to design and conduct experiments, as well as to analyze and interpret data

c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

d) an ability to function on multidisciplinary teams

e) an ability to identify, formulate, and solve engineering problems

f) an understanding of professional and ethical responsibility

g) an ability to communicate effectively

h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

i) a recognition of the need for, and an ability to engage in life-long learning

j) a knowledge of contemporary issues

k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice [7].

Figure 1: Subassemblies of the Boeing 787 Dreamliner and their country of origin.

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CHANGES IN EDUCATIONAL INSTITUTIONS
The revised accreditation frameworks of both the Australian and American accreditation bodies clearly demonstrate the growing global emphasis on broadening the engineering knowledge base and providing more holistic education. More than 50 per cent of attributes relate to non-technical knowledge or soft skills. In line with these accreditation requirements, current and future engineering curricula must focus more on interdisciplinary and non-technical knowledge. Furthermore, institutions must improve their pedagogy, learning materials and evaluation styles to further improve students' soft skills, such as communication, leadership, team spirit, project management and global outlook.

ABET [7] currently requires US engineering institutions to ensure that non-technical subjects make up at least 12 per cent of an engineering degree. However, an analysis of the curricula of several US engineering institutions reveals that, many institutions actually have more than that. For example, Massachusetts Institute of Technology has 12 non-technical subjects in its engineering degree, including 8 from humanities and social sciences, and 4 that relate to communication skills, which is more than ABET prescribes. Stanford and Cornell both prescribe one compulsory subject that relates to technology and society. And Georgia Tech allocates 24 credit points for non-technical subjects: 12 credit points for humanities and 12 credit points for social sciences, with compulsory components from ethics, history and constitution.

Subjects that relate to environmental studies in order to promote sustainable infrastructure development are a new milestone in engineering curricula. For example, Australia's Queensland University of Technology recently introduced a compulsory course for all engineering students that examines the main aspects of sustainable living as they relate to the engineering profession. Students are also encouraged to further explore sustainability issues in their final year project.

To prepare engineering students to work in a global economy, the University of Rhode Island and several other American institutions encourage students to spend at least one semester in foreign universities. Many American and European universities have developed exchange programs to help students better understand different cultures, languages and professional practices. The initial results of these programs are very promising.

Curricula designers can also augment soft skills and environmental awareness by embedding them in existing technical subjects; for example, improving students' communication skills by asking them to present an assignment in the form of a research paper or conference presentation. Many institutions currently see seminar presentations for technical and non-technical audiences as an effective way to improve engineering students' communication skills.

In Australian engineering schools, assessment pieces consist of essays, short answer tests, objective assessment, seminar presentations and learning portfolios. Schools strongly emphasise deep learning, which is usually assessed through open-book assignments rather than end-of-semester, closed-book examinations. Staff are encouraged to use real world case studies and application-oriented learning to balance performative and decontextualised assessment. Challenges facing engineering education in India

Due to the over-centralisation of the higher education sector, India's curricula reforms are much more challenging than those of most Western countries. This section describes some of the main impediments to the process of making engineering education more relevant to the 21st century in India.

LACK OF HOLISTIC CURRICULA
India's curricula reform process has had a slow start, as demonstrated by industry reports that state that today's engineers have not been appropriately educated and prepared to meet the industry's real-world challenges. The quality of India's engineering education has been questioned by industry as well as international benchmarks [8]:

...The main problem is that of employability. Studies have indicated that only one in four graduates from India's colleges is employable. A National Association of Software & Service Companies (NASSCOM) study found that India still produces plenty of engineers — 400,000 a year. But most are deficient in the required technical skills, fluency in English or ability to work in a team and deliver basic oral presentations.

It is worth noting that NASSCOM is not arguing the technical content of the curricula but is arguing that more than 70 per cent of graduating engineers are unemployable due to a lack of non-technical knowledge and skills.

Recently, some Indian universities have introduced compulsory courses that relate to soft skills and environmental awareness into the Bachelor of Engineering curricula. Some technical universities have introduced compulsory subjects that relate to ethics, professional communication and economics. However, this quantity is too little to make any real impact on a student's learning.

Historically, engineering education in India has been compartmentalised with an overemphasis on technical content. As a result, most engineering institutions today, including the Indian Institute of Technology, do not have the variety of non-technical subjects from humanities, social sciences, literature and languages to offer students—subjects that are available to engineering students in the United States and Europe. For example, a student at Carnegie Melon University in Pennsylvania can study a Bachelor of Music alongside a Bachelor of Engineering. At the Massachusetts Institute of Technology, every engineering graduate is expected to study a reasonable amount of philosophy, history
and literature. At Australia's Queensland University of Technology, a student can do a Bachelor of Engineering (Electrical) together with a Bachelor of Science (Mathematics).

In India, until now, there has been reluctance at an institutional level to broaden the engineering education base. Part of the problem lies as majority of engineering institutions do not teach courses related to physical sciences, social science, art and management. As a result the Indian engineering institutions do not provide the double degree programs that give students in Australia, America and other countries more mobility in future careers. Nor do they provide a system of credit transfer or advance standing. Even in prestigious national institutions such as Indian Institute of Technology or Indian Institute of Management, a student must study all the subjects of a degree course from the same institution [10]. And, unlike Western universities, Indian students are not encouraged to study a small part of their course in a different college or university as an exchange student. This issue has also been raised in the Yashpal committee report [11] making suggestions, for example, to make Indian Institute of Technology to start degree courses other than engineering.

**CENTRALISED CONTROL OF CURRICULA AND EXAMINATION**

Curricula design in Indian engineering institutions is much more complex and difficult than in many other countries. Most government institutions do not have sufficient number of teachers. The unaided private engineering colleges (which produced 85 per cent of India's engineering graduates in 2007) have no control over or input into curricula design. The common curricula is prescribed by technical universities (which often manage more than 100 colleges), whose primary aim is to smoothly and efficiently conduct end-of-term examinations and declare the results on time rather than to improve student learning. Presently, most unaided private engineering institutions also lack quality teachers and learning resources, which makes these institutions ill equipped for academic autonomy [11].

The first step in curricula reforms for India is to decentralise the education system by giving teachers more freedom and responsibility for student learning and evaluation. Teachers in world-class institutions not only teach classes but also plan their own subject's syllabus, design and execute assessment, and, based on student feedback, continuously improve student learning. Currently, the Indian system is peculiar in that three different people or agencies perform the tasks of designing the syllabus, teaching the class and conducting examinations. The challenge is to decentralise the academic governance with maintaining a quality assurance mechanism that enables teaching, assessment and curriculum design to take place at an institutional level.

**THE FAULTY ASSESSMENT SYSTEM**

The assessment of student learning is not an isolated activity. It should be aligned to achieve course objectives in a systematic manner. However, from student's point of view, what and how students currently learn in a course depends primarily on how they believe they will be examined in the subject. For most students, the actual curriculum is how and what is being assessed or examined [12]. Similarly, a 2002 study by J. Biggs [13] revealed that assessment is a prime motivator for student learning. Unfortunately, the examination system in most Indian institutions is archaic and rigid. It promotes rote learning, rewards only the reproduction of memorised information and inhibits higher orders of learning such as synthesis and evaluation.

Unfortunately, some technical universities have mandated that multiple choice/objective type questions must make up at least 20 per cent of a final examination in all subjects to reduce teachers' marking loads and cases of erroneous failures. Such a rigid approach on administrative grounds may not be appropriate for all subjects and undermines the purpose of assessment, which should complement learning.

Until India's systemic problems are rectified, curricula reforms, such as incorporating non-technical content to produce more 'rounded' and employable engineers, will be extremely difficult to achieve.

**CONCLUSION**

To face the complex challenges of the 21st century, engineering curricula must be drastically revised. Some 'out of the box' thinking is required to synergise technical and non-technical content to meet society's new requirements. The above analysis shows that engineering institutions in the United States have already taken the lead in this direction. European and Australian institutions are also changing their curricula, albeit slowly, to prepare their engineering graduates to meet this century's challenges.

In contrast, while India has seen sporadic curricula reforms, most Indian engineering institutions are falling behind. This is not necessarily due to a lack of awareness but more to administrative set-up, overcentralised academic power, and rigid regulations that hinder innovative academic practices and student learning.

The most urgent need is to decentralise and overhaul India's technical education system, which will include curricula reforms, to improve students' higher level learning so they can solve the 21st century's real-world challenges.

Patricia Galloway, former President of the American Society of Civil Engineers, best summarises the importance of future reforms in engineering education:

A solid understanding of globalization is key to an engineer's success in today's global society. Globalization involves the ability to understand that the world economy has become
tightly linked with much of the change triggered by technology; to understand other cultures, especially the societal elements of these cultures; to work effectively in multinational teams; to communicate effectively—both orally and in writing—in the international business language of English; to recognize and understand issues of sustainability; to understand the importance of transparency while working with local populations; and to understand public policy issues around the world and in the country in which one is working. It will be these fundamental capacities that will enable 21st-century engineers to develop into professionals capable of working successfully both domestically and globally, highly respected by the general public and regarded...the world over as professionals of the highest order [14].

REFERENCES


END NOTE

The Taxonomy of Educational Objectives (Cognitive Domain) developed by Bloom and colleagues define a hierarchy of six levels:

1. Knowledge—repeating memorised information

2. Comprehension—paraphrasing text, explaining concepts in jargon-free terms

3. Application—applying course material to solve straightforward problems

4. Analysis—solving complex problems, developing process models and simulations, troubleshooting equipment and system problems

5. Synthesis—designing experiments, devices, processes, and products.

6. Evaluation—choosing from among alternatives and justifying the choice, optimising processes, making judgments about the environmental impact of engineering decisions, resolving ethical dilemmas

Levels 1–3 are commonly known as lower-level skills and Levels 4–6 are higher-level skills [13]