Attributes of Engineers and Engineering Education for the 21st Century World

Dr. PE Seeram Ramakrishna, FREng[1], Dr. Mudrika Khandelwal[2]

[1]National University of Singapore
[2]Indian Institute of Technology, Hyderabad
[1]seeram@nus.edu.s

Abstract- *21st Century is witnessing enrollment of Net generation (19 years old) of students into a variety of engineering programs. They have diverse learning aspirations and needs. They wish to learn at their own pace and comfort with peers while leveraging the technology enhanced learning tools. They are open to diverse views, flexible careers, research and innovation careers, and entrepreneurship. They are aware that their workplace will be different from the earlier generations as the businesses leverage supply chains spanning the world and compete to differentiate in the local markets. 21st Century workplaces seek employees with cross-cultures work abilities and global knowledge and experience as they need to interact and move internationally. The Net generation will live longer than earlier generations, and need to be economically active for longer periods. Learning life-long and regularly upgrading skills and knowledge is the new normal. The Net generation of students have a choice of diverse engineering education providers such as public, private, not-for-profit, for-profit, online, part-time, international branch campuses, and their combinations. They have access to worldwide comparison of engineering schools at the disciplinary level, internationally recognized and accredited engineering programs, and opportunities for the global experience at home and abroad. They are comfortable with digital technology and prefer blended learning methods. Recent decades also saw widening of engineering field covering many new disciplines which flourished at the interfaces with other disciplines. The strong demand for professional qualifications led to the scenario of undergraduate engineering education being akin to liberal arts education with diverse career options. Yet, according to the several media reports, the employers are able to find only a fraction of engineering graduates with requisite knowledge, skills, abilities, and attitudes suitable for employment. In other words there is a need to rethink the way the students are inspired and developed, faculty members are prepared, and curriculum and pedagogy are tailored to the needs of the 21st Century workplaces and new generation of students. Systematic engineering education research and thought leadership is needed to produce globally competent engineers. Sharing of best practices and continual improvement in all aspects of engineering education is desired for preparing engineers for the 21st Century. Authors' affiliated institutions implemented many aspects of engineering education captured in this paper.*

Keywords : engineers, global engineers, engineering education; graduate education; researchers; innovation

1. Introduction

High quality, creative and entrepreneurial workforce, scientific research capacity and capabilities, and an ecosystem conducive to innovate products, services & governance are key enablers of competitiveness of countries in 21st Century globalized world. Hence the knowledge, skills and experience the engineering students acquire at the universities are under scrutiny (1).

There are more than six thousand engineering education providers worldwide enrolling millions of students. Majority of them came into existence over the last fifty years. India alone has about 3390 engineering education providers who are either independent or affiliated to a university (2). They are diverse in terms of nature of institution (public, semi-public, private; religious, teaching, research, and research-intensive), size (boutique, medium and large enrollments), governance (autonomous and semi-autonomous), funding mechanisms, range of programs, location, mission, vision, mode of delivery (full time, part time, online, mixed mode), level of resources, quality of students, gender of students, quality of faculty members, flexibility of programs, national and international partnerships, accreditation and quality assurance, etc.

Global comparison of thousands of universities around the world emerged in the beginning of 21st Century. The world ranking lists were generated by comparing each university as a whole with others. More recently, the universities are compared at the individual discipline level. Increasingly universities and engineering schools are pressured to move up in the rankings. Institutions around the world are chasing the top few universities, which take fewer students and primarily are research universities. This is leading to isomorphism of institutions, and losing the sight of broader mission of universities and education providers. It is important to recognize that the students have diverse needs, and societies need diverse education pathways and often different issues to address. Efforts should be aimed at developing incoming students to their full potential, and evaluate the higher education providers based on the extent of value added to the students and the society. This

need is clear to the engineering education scholars and thought leaders, but the criteria for evaluating the value add by an institution is not clear. One size certainly does not fit all when it comes to assessing the value addition in education. And some aspects are easier to measure than others. Quality assurance or accreditation with appropriate benchmarking serves better purpose than the mere rankings (see Table 1). It is more important for the universities to differentiate education offerings, and continually improve the education quality by benchmarking with peers and aspirant institutions meaningfully. Universities are to find ways and means to facilitate an interdisciplinary learning environment via flexible curriculum. 21st Century world needs university education to facilitate students' disciplinary competence as well as social conscience and compassion.

Especially, engineering as a discipline has been dynamic and continuously evolving over the centuries (see Figure 1), and several new disciplines have emerged to address the needs and expectations of industries, businesses, economies, and nations. There is need to prepare engineers with ability to customize engineering solutions to the local, social, economic, political, cultural and environmental contexts (3). The time is right to emphasize on the importance of global dimension within all engineering and technology disciplines to address challenges of 21st century (4-9).

Table 1. Comparison of rankings and accreditation

	Rankings	**Accreditation**
Assessor	Market oriented organizations (QS; THE; ARWU, etc.)	External peers
Performance Review	Based on databases	Comprehensive – internal review, self-evaluation report, benchmarking, site visit & audit
Outcome	Ranking Lists	Accredited or Not Accredited
Criteria	One dimensional; Based on Ranking criteria & weights	Multi-dimensional; Based on evidence and demonstration of outcomes
Contents	Well received by the media, public and students	Difficult to comprehend
Purpose	Business motive	Quality assurance & enhancement of standards; social accountability
Perception	Independent; Benchmarking tool for national & global comparisons	Limited by peers' perception of performance
Period	Annually	e.g. once in 5 years
Effect	Better students, staff, resources and influence	Mobility of graduates; resources

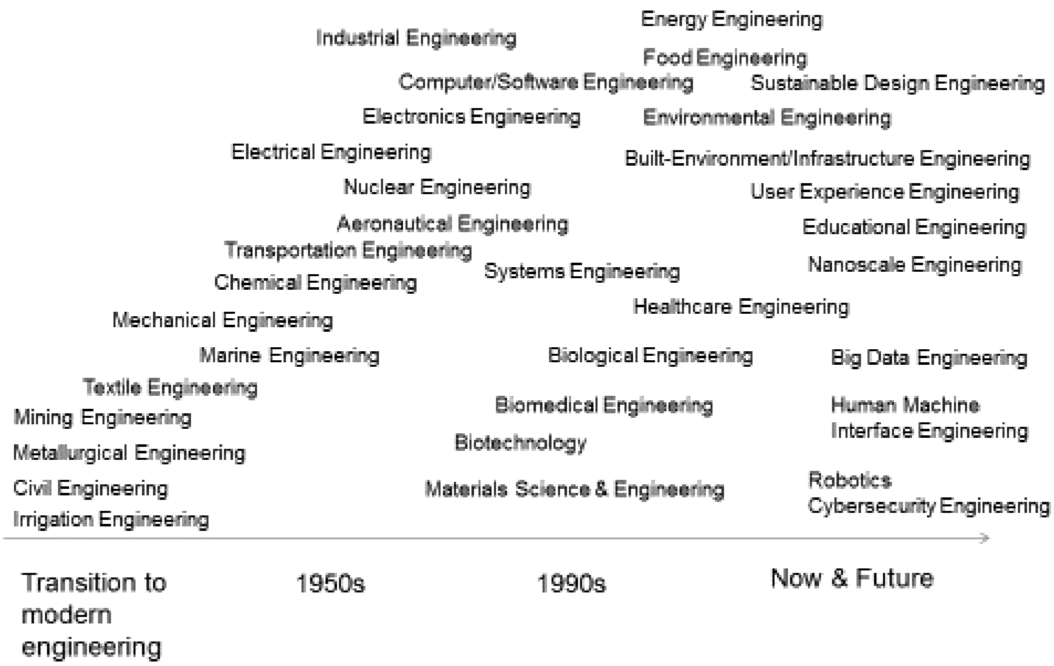

Figure 1. Dynamic nature of engineering field

For the aforementioned reasons, the engineering education providers needs to play a pivotal role in enhancing a) relevance of engineering education to the changing businesses, economies and societies;

b) teaching abilities of academics; and c) tailoring of curricula & pedagogical approaches to the future engineers' needs and expectations.

Emerging countries such as India have the largest proportion of engineering education providers, programs and students, yet they lack engineering education research centers and programs. Many engineering education providers are experiencing shortage of adequately qualified faculty members. Hence, they are employing either graduates without PhD degree or PhD degree holders with strong research credentials as faculty members. In both scenarios, the faculty members lack the pedagogical skills of teaching students and deeper perspective/

understanding of engineering education. There is a need for professional development of future faculty members with engineering education knowledge and skills in global context. In this regard, future engineering faculty members should be encouraged to take a course or minor in engineering education while doing PhD in engineering research (see Table 2 for examples).

2. Attributes of 21st Century Engineers

The economic environment of 21st Century is far different from the past centuries. Businesses and industries are now leveraging supply chains spanning the world, and integrating innovations from around the world. They source finances and diverse workforce worldwide. They customize products to the markets they serve, as opposed to the past practice of standardized products made in one place and sold worldwide.

Table 2. Examples of professional development of engineering educators (10, 11)

Institution	Degrees	Notes
Virginia Tech Department of Engineering Education	Certificate	Engineering Education Graduate Certificate
University of Michigan Engineering School: Center for Research on Learning and Teaching (CRLT)	Certificate	Certificate in Engineering Education Research
University of Georgia Faculty of Engineering: Engineering Education Research Cluster	Ph D Masters	M.S. and Ph.D. in Engineering with Area of Emphasis in Engineering Education Research
Texas A&M University College of Engineering	PhD	Ph.D. in Interdisciplinary Engineering
Purdue University School of Engineering Education	PhD	Ph.D. in Engineering Education
Carnegie Mellon University Engineering School: Program in Interdisciplinary Educational Research (PIER)	PhD	Ph.D. in Interdisciplinary Educational Research via Mechanical Engineering program
Arizona State University Ira A. Fulton School of Engineering	Ph D Masters	Example: Ph.D. Mechanical engineering with concentration in Engineering Education
Aalborg University (Denmark), UNESCO Chair in PBL in Engineering	Ph D Masters	Problem Based Learning in Engineering Education

This has been possible due to the availability of educated workforce, investments, and innovation capabilities in various regions of the world, and globalization of trade, finance and talent, and availability of modern transportation, information and communication technologies (ICT). These enterprises require engineers with strong communication skills, open to diverse approaches, and who can lead multicultural teams. They must be proficient in ICT skills as well as problem solving skills with real world experience. They need to be innovative, relevant, persistent, and life-long learners to keep up with the rapid technological progress and evolving 21st Century world. They will become engineer-leaders with experience and sustained achievements. Recently the American Society for Engineering Education (ASEE) produced a report entitled 'transforming undergraduate education in engineering', with an aim to develop a clear understanding of the qualities engineering graduates should possess and to promote changes in curricula, pedagogy, and academic culture needed to instill those qualities in the coming generation of engineers (Figure 2). Key knowledge, skills, and abilities desired of future engineers include a) engineering science fundamentals, b) engineering, c) context in which engineering is practiced, d) communication, e) teamwork and leadership, f) flexibility, g) curiosity & desire to learn for life, and h) ethical standards & professionalism.

Accreditation bodies with motivation to enable mobility of engineers and working professionals via international recognition of qualifications have documented the desired outcomes of engineering education. For example, Accreditation Board for Engineering and Technology, ABET (12) lists various competencies namely a) ability to applyknowledge of math, science & engineering, b) ability to design & conduct experiments, analyze data, c) ability to design

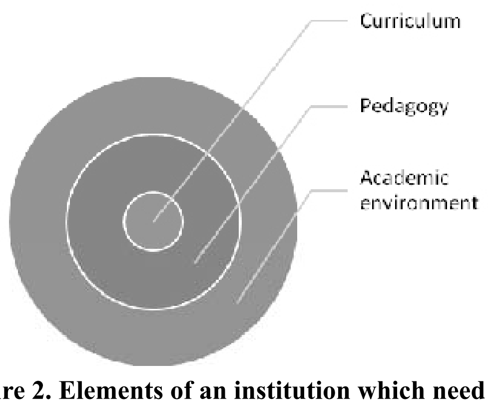

Figure 2. Elements of an institution which need to be changed for better engineering education

a system component or process, d) ability to function on multi-disciplinary teams, e) ability to identify, solve & formulate engineering problems, f) understanding of professional & ethical responsibilities, g) ability to communicate effectively, h) understand the impact of engineering solutions in a global & societal context, i) life-long learning, j) knowledge of contemporary issues, and k) ability to use techniques, skills & engineering tools necessary for engineering practice. Similarly, Washington Accord (WA) member nations identify certain abilities expected of graduate from an accredited program. They are grouped under broad headings namely academic education, knowledge of engineering sciences, problem analysis, design and development of solutions, investigation, modern tool usage, individual and team work, communication, the engineers and society, ethics, environment and sustainability, project management and finance, and life-long learning.

Recently India was accepted as a full signatory of the Washington Accord (13). This means that the Indian engineering graduates will be considered to have met the academic requirements necessary to take up the practice of engineering in any of the signatory countries.A report by national association of software and services companies (NASCOM), only 15-20 % of engineering graduates are employable because of the rest not being industry fit (14). In recent years similar reports emerged in various countries around the world suggesting that only a fraction of engineering graduates are suitable for employment. This means more efforts must be made to educate engineers with 21st Century skills and knowledge. The following sections give deeper attention to the undergraduate and graduate engineering education.

3. Attributes of Undergraduate Engineering Education

Recent three decades saw exponential growth in engineering enrollments in worldwide especially in emerging countries. This led to a wide variety of engineering education providers, students, engineering disciplines, curricula, pedagogic and delivery approaches.

The unbridled expansion led to a) compromise in the quality, rigor and standards of education, b) graduates without jobs that fit their training and c) education unable to inspire students who seek personal fulfillment and motivated to contribute to the society. The real-world demands on engineering graduates and engineering education have drifted apart. Engineering curriculum and pedagogies should be updated and fine-tuned to develop 21st Century engineers with necessary depth and breadth skills and knowledge (T-Engineers) as shown in the Figure 3 (7). Most engineering education providers have focused on technical depth courses involving engineering science fundamentals and engineering. Some institutions recognize the need for imparting ICT and communications skills and students' exposure to the professional ethics and standards. They are also making efforts to develop systems thinking, problem solving, creative and innovative skills of the students by introducing design projects, research projects, multidisciplinary projects, and industry sponsored projects, and flexibility in the curriculum for self-directed learning and peer to peer learning. Critical thinking skills of the students are enhanced via breadth courses. Yet these efforts seem to fall short of motivating students. Students' interest in engineering could be enhanced by relating classroom teaching to the real life experiences and societal challenges, by updating courses with new knowledge, by providing experimental learning involving problem solving, applying knowledge and skills, hands on approach, industry internships and internships abroad, by providing interdisciplinary and global learning experiences, and by providing opportunities for entrepreneurship, entrepreneurship, team work, and test bedding solutions. The exponential demand for professional qualifications, particularly for engineering led to rapid growth of a) private higher education providers and b) international branch campuses (IBCs) of foreign universities in emerging countries around the world. They are active

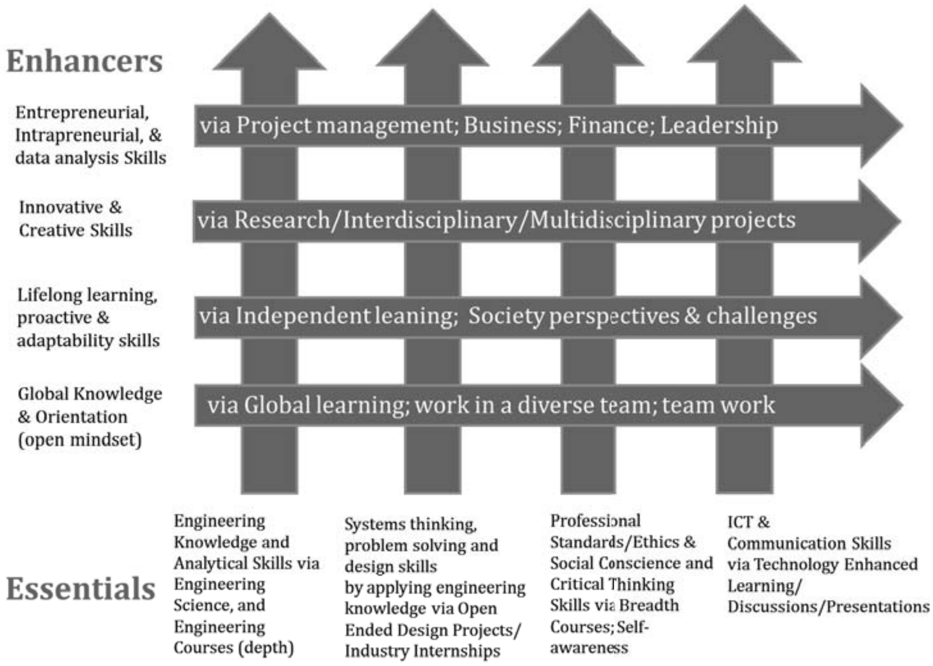

Figure 3. Key features of training T-Engineers

in education and entrepreneurship, and not so much involved in the research led innovations and graduate education. Hence we captured these developments in the following sections.

4. Role of Private Higher Education Providers

The definition of private higher education is not clear cut. Based on the source of funds, degree of autonomy in governance, and how they deal with the profits, the private higher education institutions can be grouped broadly into not-for-profit institutions and for-profit institutions. National laws and regulations for private higher education vary from one country to another. The proportion of higher education students enrolled in private higher education institutions in various countries around the world are listed in Table 3. Among the high income countries, the West European nations have the lowest proportion of students attending private institutions. USA stands out among the high income countries with a good proportion of students enrolled in private higher education. Reasons are historical with West European nations strongly subscribing to the policies of public good and state responsibility to provide for higher education. USA experimented successfully with co-existence of private, public and more recently for-profit private higher education providers. In the case of emerging countries the proportion of higher education students attending private higher education institutions is significant. There are multiple reasons for this situation.

Governments are unable to find resources to support massive demand for higher education as the countries develop, and hence allowed private higher education providers to share the cost burden to expand the higher education sector. Moreover there is a perception the public higher education institutions are resistant to change and unable to recognize the

Table 3 Proportion of higher education students enrolled in private institutions in various countries around the world

	0-15%	>15<35%	>35<80%
Emerging Countries	Cuba Bhutan North Korea Argentina Thailand Turkey South Africa Kenya Nigeria Uganda	China (15%) Vietnam (15%) Cambodia (15%) Poland (20%) Egypt Kenya Hungary	Indonesia (70%) Malaysia (50%) India (60%) Philippines (70%) Pakistan (35%) Iran (50%) Kazakhstan (50%) Mexico Brazil Peru Chile
High Income countries	Germany New Zealand Australia	USA# (26%) Portugal (30%) Russia	Japan (70%) South Korea (77%) Singapore (40%)

positive developments at the world class universities in developed nations. Businesses, associations, and philanthropists established private higher institutions to provide for different learning needs of diverse students and leverage the opportunities. The rapid growth led to institutions and engineering education programs with varied commitment and quality. There is growing recognition for the need to improve their quality and relevance.

5. Role of International Branch Campuses

An international branch campus is a degree offering satellite campus of a university in a foreign (host) country to address the local needs and leverage opportunities while furthering the goals and mission of home campus (primary location of a university). It is a key form of trans-boundary higher education (15). According to a recent estimate by the Cross- Border Education Research Team (C-BERT) thereare more than 200 international branch campuses in about 60 host countries from about 25 home countries. It is interesting to note that there are less than forty international branch campuses in the beginning of 21st Century.USA, UK, Australia and India are major exporters of higher education with about 76, 28, 17 and 10 international branch campuses respectively. United Arab Emirates, China, Singapore and Qatar are major importers of higher education with 32, 31, 13 and 10 international branch campuses respectively. This trend is partly due to the ambition of Middle Eastern countries and Singapore to build global education hubs. Funding strapped higher education institutions in the high income countries are seeking opportunities for extra income in the emerging countries. The experience of international branch campuses in the overall landscape of higher education is relatively new. Hence their effectiveness in delivering quality higher education is inconclusive. There are many differences among the international branch campuses. For example some are wholly owned by the home campus university, some have partnership with host country government, some have private investors where as several others have local academic partners to deliver the educational programs. Quality assurance of trans-boundary higher education is a new challenge and the accreditation bodies are in the catch-up mode. Critics raised concerns such as how will the developing world really develop its own indigenous methods of intellectual discourse if the IBCs are viewed to be superior in the host countries in comparison to the national universities? IBCs are offering the bread & butter courses, especially those which require less investment and competing directly on price with the local universities. They may also drain the talent, students and academics from the national universities. IBCs provide education opportunities to those who can afford it and what about the equitability of access? Leaders of the international branch campuses also expressed their concerns. For example they lack equal access to the student loans and scholarships schemes and competitive public research funds. How to bring in their research culture and to perform a role in impactful knowledge generation and innovations. More than twenty international branch campuses have ceased their operations. The ongoing debate places spot light on the quality and relevance of engineering education.

6. Technology Enhanced Learning

In recent years with the availability of course management software's such as Blackboard, Eliademy, Edvelop, Moodle (free-to-download Open Source Course Management System), etc. the student and teacher interactions are being redefined. Assortment of terms are used to describe the application of ICT to teaching & learning which include e-learning, online learning, cyber learning, virtual learning, computer-based instruction (CBI), computer-based training (CBT), computer-aided instruction (CAI), internet-based training (IBT), web-based training (WBT), fully online distance learning, digital educational collaboration, multimedia learning, m-learning (mobile technologies). Essentially all these are forms of technology enhanced learning and teaching methods to facilitate various pedagogies asynchronous learning, blended or hybrid learning,

flipped or inverted learning, personalized learning, collaborative, peer learning, problem based learning, outcome based education, active learning, etc. In other words they capture the imagination and needs of the Net-generation students. International branch campuses and private higher education providers are early adopters of technology enhanced teaching and reach out to the students.

In USA, the for-profit institutions of higher learning are early adaptors of technology enhanced learning. In 1995 the for-profit institutions share of students is ~ 2% (or ~ 304,000) of all enrolled students in higher education. In 2010 their share of students grew to ~ 10% or 2.1 million students.US media has been highlighting that majority of American universities are slow in fully adopting technology enhanced learning. Several reasons have been sited which include a) reluctance on the part of teachers to change, b) curriculum and pedagogy lagging behind, c) not yet fool proof against cheating,

d) issues associated with quality assurance and assessment, f) lack of trained staff to support, g) financial viability, h) technology divide among the students, i) limitations on extent of social interactions among students and between teacher and students, and j) a synchronic feedback.

Judging from the progress of ICT technologies over past few decades it is conceivable that many of the above mentioned bottlenecks will be overcome. Universities in the emerging countries should start to embrace technology enhanced learning and teaching, and be ready for the future.

7. Short Courses for Lifelong Learning

Baby boomers (50-68 years old), X-Generation (38-49 years old) and Y-Generation (20-37 years old) are facing the situation of career uncertainties in rapidly changing, ubiquitous technology world. During the course of long lives, some of them wish to explore passions which could not be realized due to commitments, and while others wish to make a career change. They need opportunities to sample courses and upgrade knowledge and skills as and whennecessary at their own pace and convenience. Short courses and online learning or technology enhanced learning are emerging as important means for these adult students. Universities should plan for and cater to the growing number of adult students.

8. Graduate Education

Most emerging nations, including India, and universities focus their attention on the undergraduate education and relatively less or no attention is given to the training of quality graduates and young researchers (10, 16).IITs have emerged as world class institutes of great reputation for undergraduate engineering curriculum, but this achievement is still not seen for post graduate engineering education (17). Most students who want to pursue research seriously tend to go abroad because of several reasons which include access to high quality research infrastructure and facilities, opportunities to work on most interesting scientific problems, reputed mentors, resources to translate research innovations into products, and employment opportunities upon graduation.

The quality of graduate training should be given greater attention as some graduates will go on to become academics and influence and inspire future generations. Many of them will also become chief scientists, chief technology officers, and chief information officers in diverse companies around the world. They contribute to the organizations and support their chief executive officers in foresight, strategies, vision, and new innovative products. Along the way some of them will become entrepreneurs by setting up start-up companies based on their own experience and research led innovations. Hence from these diverse considerations, there is a need for training quality graduates and junior researchers in a more holistic way and future ready, and what should that be?

World class universities have been paying attention to the students' abilities to use modern tools and methods, and advanced scientific knowledge and skills imparted in specialized domains (16-23).However solving many challenging problems such as clean water, energy, transportation and environment, healthy life and affordable healthcare, and ubiquitous security and comfort require integrative approaches. Most interesting and useful innovations in recent years are a result of multidisciplinary and interdisciplinary efforts. Hence the students should be given opportunities to collaborate and interact with other disciplines. For sustaining research led innovation career which typically spans over four decades an individual needs to raise funds regularly in a competitive and resources limited world. This requires effective communication and marketing skills to convince diverse investors and stakeholders while maintaining ethics and research integrity and respecting intellectual property rights of others. In order to develop and implement innovative solutions to the societal challenges often researchers must be able to work with others from different cultures, languages, norms and safety standards. Hence the graduate researchers need exposure to overseas research cultures and practices, and intellectual property protection and transfer processes. The graduates should be mentored to aim the right questions with the right approach and attitude. They should understand the importance, relevance and impact of their work. Curriculum should be flexible enough for those desire to pursue entrepreneurship and translation of research outcomes into practice. All these aspects of a quality graduate education are captured in Figure 4. University's internal structures should have porous boundaries to facilitate interdisciplinary research and learning. Academic environment should be conducive for collaborative research and creating new frontiers. Perhaps global graduates be developed via enhanced interactions with overseas peers via a) visiting faculty, b) graduate student exchanges, c) collaborative research, d) joint publications, e) joint conferences, f) joint graduate courses, etc.

9. Innovation led Entrepreneurship at Engineering Institutions

History has witnessed several innovations from engineers including Leonardo da Vinci and Henry Ford (24). The crux of engineering is to utilize modern science to develop products for the betterment of the society. A professional education laid with this objective is bound to inculcate certain skills which are very important to be a good entrepreneur. A quick look at the recent boom in start-ups in Indian market reveals that most were founded by engineers. Some of these include Olacabs, Myntra, Flipkart, Redbus, Wingify, Zomato, thinkLAB and the point to note is the diverse spectrum of products. It should also be stated here that none of the entrepreneurs of the above mentioned start-ups had formal business education.

Today several engineering institutes have entrepreneurship cell to promote entrepreneurial exposure and activities. And amongst them the top

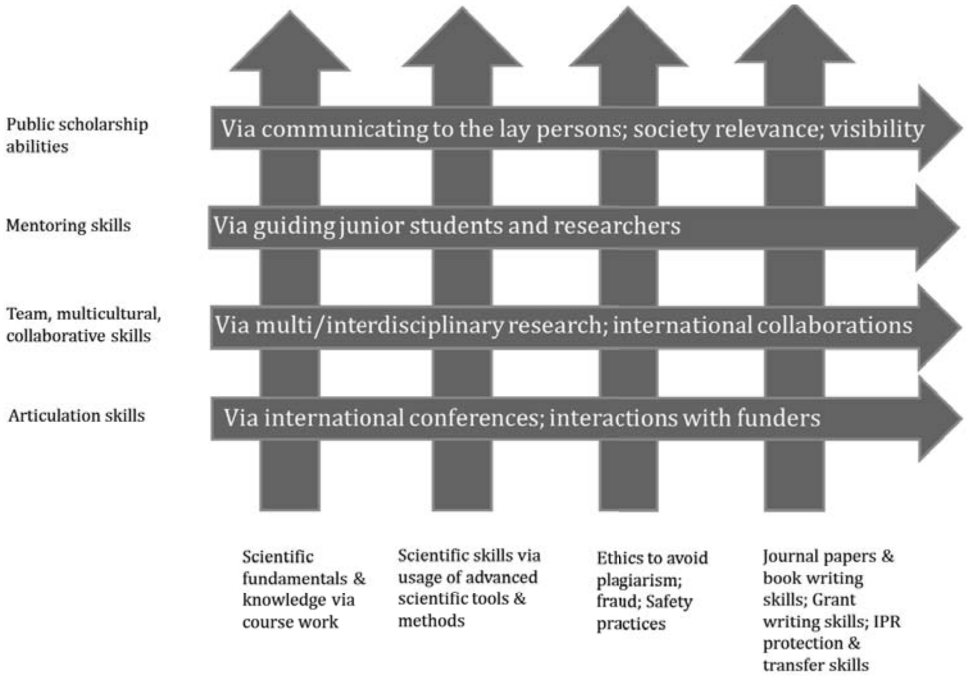

Figure 4. Key features of quality graduate education

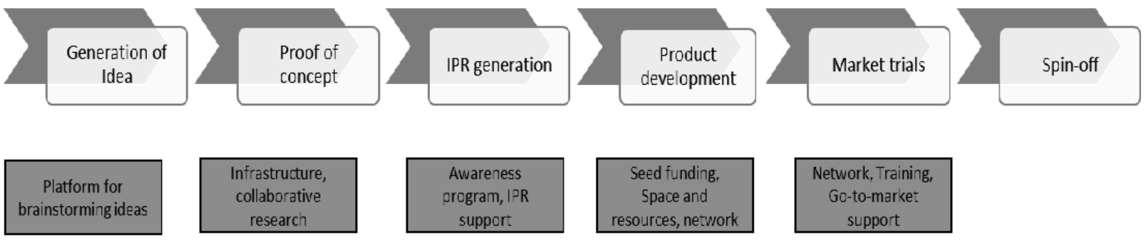

Figure 5. Flow from idea generation to spin off

ones, also have an incubation center and research parks to cradle the start-ups. The universities provide support to attract investment to convert start-ups into full-fledged companies. An important reason to promote on campus entrepreneurship is to facilitate conversion of research into products. Increasingly, researchers are not only interested in fundamental research but to develop intellectual property followed by product spin-off. The startups not only bring product to people, but also generate employment. According to the U.S. Small Business Administration, businesses with less than 500 employees employ more than one half of all private sector employees, and pay 44 percent of the total private payroll in the United States (25). Given the market situation in India, start-up can play a very important role.

One of the measure of innovation and entrepreneurship from universities is the number of patents and spin offs. University of California and MIT had over 390 and 280 patents in 2013 respectively. On comparison in this metric, the institutions in India lag far behind. The only Indian institute in top 100 is Indian Institute of Science, Bangalore, with 21 patents (26). Several reasons could be attributed to this – lack of focus on generating IPR, lack of awareness on the process, lack of financial support and lack of exposure.

This is the right time to focus on innovation and entrepreneurship. Universities need to develop the right ecosystem for innovation and translation into market product. The ecosystem should comprise of start-up incubation support infrastructure, start-up grant, awareness programs about IPR and business and most important network. Orange boxes in Figure 5 indicate several areas in which the universities can contribute and facilitate. In recent years the networks like TiE (The Indus Entrepreneurs) came forward to support aspiring engineers to become entrepreneurs. TiE says that although a few engineering institutes are taking a lead to inculcate entrepreneurial culture in students, the process is in nascent stages in India and the education system, government and corporate sectors have to come together to support it (27). Mentoring programs, funds, expertise, and efforts will accelerate the technology entrepreneurship.

10. Conclusions

Engineering education is at the crossroads. Transformation in engineering education is needed in order to enhance students' interest, and to improve relevance of engineering education to the respective societies. There is need for a)embracing technology enhanced learning and teaching, b) training engineering educators, c) developing flexible and customized curriculum to suit Net generation students' needs and expectations, d) plan for growing number of adult students, unconventional students, and their lifelong learning, e) updating ranking and accreditation criteria and standards to enhance the quality and social impact, f) customized engineering education strategies appropriate for an institution and country, g) thought leadership in engineering education and h) universities to facilitate research in frontier domains to spur the next wave of innovations. Sharing of best practices around the world, and continual improvement in all aspects of engineering education have never been this important in the history of engineering profession.

Acknowledgements

Some contents of this manuscript are reproduced from the references (28) and (29).

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