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Engineering Education and Skill Development

Piyush Sinha
School of Science,
H.N.B. Garhwal University, Pauri Campus, (Uttarakhand), INDIA

(Corresponding author: Piyush Sinha)
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I. INTRODUCTION

Engineering education now a days is at the forefront of having dynamic changes in view of knowledge explosion, ever-increasing complexity in which engineers work and fast changing global economies. Although basic engineering concepts do not change but the fast changing environment at the workplace demands for new paradigms to shape professional skill sets and competencies for new engineering graduates. Engineers in the present scenario are required to play an important role in creatively solving complex challenges related to energy, food and health care, changing climate and disaster management. Hence they need to cultivate communication and social skills and work with an understanding of multiple disciplines in collaborative teams that are culturally and philosophically diverse. Moreover they should be able to explain science and technology to a society that is increasingly more doubtful of its impact and intentions despite enjoying its comforts that come with progress in engineering and technology. Engineers must therefore learn new sets of engineering competencies and professional skills to take on the grand challenges in a sustainable manner. To prepare budding engineers to meet such growing demands, it is clear that a traditional engineering curriculum which is content heavy will not be sufficient. There are already indications[6] that there is a significant gap between what undergraduate engineering students are taught assessed and what the professional engineers and industry practitioners expect them to be capable of. This gap will significantly widen unless intentional, well targeted measures are put into place in engineering education to specifically foster 21st century skills.

II. 21st CENTURY SKILLS

In today's new economic environment, innovative thinking, problem solving, decision making, sharing of information and collaborative team work are key competencies necessary for an engineer.

According to National Research Council Report [14-15], five skills namely adaptability, complex communication skills, non -routine problem solving skills, self-management or self-development and systems-thinking are becoming increasingly valuable. Numerous research studies and reports [2-3], have indentified the key skills needed to be cultivated by engineers in the 21st century globalised world. They are:

-Communication: They ability to communicate effectively in a wide variety of forms and contexts for a wide range of purposes by using multimodal communications and technologies.

-Creativity and innovation: The ability to create new ways of thinking and be able to find solution to new problems by being innovative enough to build new products and services.

-Critical thinking and problem-solving: The ability to apply higher order thinking to new problems and issues, use appropriate reasoning to analyze problems and be able to make appropriate decisions needed to solve problems (non-routine problem solving using critical thinking).

-Collaboration: The ability to work in teams where they are able to effectively generate, share and use ideas.

-Information literacy: The ability to access, evaluate, synthesize and share information from multi-disciplinary/interdisciplinary sources.

-Technology usage: The ability to identify appropriate technology tools and use them efficiently, ethically and effectively.

-Personal/Social responsibility: The ability to develop cultural competence in working with others by recognizing and respecting cultural differences while working on diverse cultural and social backgrounds.

-Career/ Life Skills: To ability to become self-directed and independent learner who can adapt to change, manage projects, take responsibility for their work, lead others and produce results.

III. PREPARING ENGINEERS FOR THE WORKPLACE

By and large, the current undergraduate engineering education focuses on students acquiring content knowledge rather than preparing them for professional practice; this often results in students taking a surface learning approach rather than deep learning approaches. The discipline-focused program structure with its narrow but heavy workload promotes a passive learning approach where less than desirable amount of thinking and collaboration happen. However, according to a study [17], active learning benefits student engagement; collaborative work is found to enhance academic achievement of students, their attitudes towards learning and retention of students to the programme. Recent studies [15], have pointed out that employers assessed the teamwork and communication skills of engineering graduates as "at least adequate". While is accepted that it is extremely important for engineering education to produce technically competent graduates, the time is apt for enriching and broadening engineering education to foster generic, transferable skills. Stanford University President Hennessey (2006) stated that solving these problems will require "*Deep collaboration and intensive investment*".

Hence to address the gaps, engineering education must make considerable changes in the programme to:

- innovate engineering curriculum to develop the necessary 21st century skills and competencies in its students;

-focus on learning(not teaching) to enhance the learning experience of the students by integrating diverse classroom techniques, using complementary technology, implementing new learning strategies and address different learning styles of students;

-develop engineering educators' skills and competencies through continuous professional development where they understand better on what it takes to practice the engineering profession as well as be able to effectively catalyse student learning (Morell & DeBoer, 2010). Faculty members must understand "How Learning works" and use such understanding to good effect (Ambrose *et al.*, 2010); and

-introduce and integrate assessments to assess the 21st Century skills imparted (National Research Council, 2011).

IV. CURRICULUM INNOVATION TO MEET 21ST CENTURY CHALLENGES

It is been widely criticized that traditional engineering education practices like lectures and lab sessions are inadequate in preparing engineering students for being effective professional. This is more so when the lectures turn out to be monologues and the laboratories are recipe driven rather than inquiry driven. Traditional classroom and laboratory practices encourage a passive form of learning within a compartmentalized curriculum. Therefore, it is important for engineering education to re-build a curriculum that focus strongly on collaborative and interdisciplinary projects, tasks and assignment. Such activities would require engineering students to be involved in active learning strategies, be engaged in high-level problem-solving skills and be able to participate in team building activities and forge collaborative partnerships amongst multidisciplinary teams.

Current global challenges such as climate change, clean energy and ageing-related healthcare issues, require creative engineering solutions that integrate knowledge form multiple disciplines. Taking this into consideration, the National University of Singapore (NUS) has introduced curriculum changes to the engineering education by introducing flexible, innovative and alternative learning pathways that strongly emphasize cross-cultural, cross-disciplinary and problem- based learning. The enhancement programmes offered at NUS broaden the engineering students' education. Programmes such as industrial attachment programme (IAP), Vacation Internship programme (VIP), Technopreneurship & Incubation programme (TIP), Innovation Programme (IP), Undergraduate Research Opportunities Programme (UROP) and Independent Work Programme (IWP) provide students with personalized and non-traditional learning opportunities. Students are free to select one or more of these programmes based on their learning interests. These programmes enable students to:

- translate theories learnt in the classroom into practice in a real world environment;

-instill the right kind of work attitude and professionalism through interaction and collaboration with industry professionals and thus be better prepared for careers in the future workplace;

-promote independent- learning as well as collaborative team-work;

-acquire skills to be able to think critically and creatively and be involved in the intellectual process of inquiry;

-understand the effective use of technology in the workplace; and

-appreciate and/or challenge current engineering practices.

One of the recent curriculum innovations introduced at the NUS Faculty of Engineering is the Design-Centric Curriculum (DCC) that provides students the opportunity to pursue a Master's degree from one of the leading partner universities after an undergraduate degree at NUS.

In putting together the DCC, its leadership designed this four year integrated curriculum to provide students' support, challenge and intensity to explore material in greater depth and make strong connections between theory and practice though thematic multi-year, multi-disciplinary design projects. Real-world practical designs, self learning collaborative work, systems thinking and engineering technology management are embedded within modules right from the first year. Projects selected under the curriculum are centered on the big and complex questions such as climate change, transportation issues, natural disaster and healthcare for the elderly. It is hoped that the DCC will invoke a spirit of innovation and entrepreneurship in students. A second example for curriculum innovation is the "Global Engineering Programme". This programme provides a global learning experience and an early exposure to research. Students in the programme have the opportunity to spend at least one semester at a partner university overseas, participate in overseas summer programs and community projects. Students are mentored by a select pool of faculty members and can participate in activities to enhance their communication and leadership skills.

V. ENRICHMENT PROGRAMMES OUTSIDE THE CURRICULUM FOR SKILL DEVELOPMENT

It is the need of the hour to develop enrichment programmes outside the curriculum for the budding engineers. For example a programme titled such as – "Learning for success" that can enable students to hone their 21st century skills should be designed. These must include sessions on communication, thinking, effective writing, critical thinking, stress management, time management, mind-mapping techniques, study and interpersonal skills and effective use of technology. Understanding the importance of communication in the 21st century, students should be exposed to strategies to apply scholarly thinking and standard language, explore different modes of communication through a series of activities planned during communication skills workshops, one-on-one consultations and summer camps. Engineering students ought to be exposed to sessions like "Preparing effective scientific presentation" that allow students to explore effective strategies for structuring their research/project presentations, to rethink the design of visual aids, and let them converge on a best delivery style that most suits them.

VI. ASSESSMENT OF STUDENTS' LEARNING THE 21ST CENTURY SKILLS

Assessment and grading are known to have a very large effect on students' approach to learning. These major handles must be leveraged upon carefully- assessment tasks in engineering should increasingly involve group work and facilitate cooperative learning. However, research studies on games and online learning communities identifies problem-solving as a key concept. Understanding student experiences in such environments of problem-solving will lead us to rethink the way we define key skills and design assessment tasks. Hence, it is important for engineering education to transform in ways- educational standards and assessment – that will enable students to acquire the much needed sophisticated thinking, flexible problem solving, collaborative and communication skills needed for the workplace. Researchers have also indentified that every assessment designed should involve three fundamental components "a model of how students represent knowledge and develop competence in the subject domain, tasks or situations that allow one to observe students' performance, and an interpretation method for drawing inferences from the performance evidence thus obtained". In a 2011 interview, the Harvard President, Faust indicated that "thinking about assessment in different ways- how we evaluate students, faculty, methods, courses and programmes" is crucial for a broad push for innovation and experimentation. According to Griffin et al. (2012), assessment tasks and situation should be a) aligned with the development of significant 21st century skills, b) adaptable and responsive to new development, c) largely performance- based, d) able to add value for teaching and learning by providing valid information that can be acted on by students, teachers and administrators, e)able to meet the general criteria for good assessments (i.e., be fair, technically sound; valid for purpose and part of a comprehensive and well-aligned system of assessments at all levels of education). Thus, it is fairly clear that students need to be weaned away from rote memorization model by eliminating assessments or tasks that focus on "Given this, calculate that" type of problems. Open-ended quizzes that stimulate students' creativity and enable them to think deeply about materials covered in lectures need to be introduced.

CONCLUSION

Considering the challenging environment at the workplace and the social and technological problems that the generation of engineering graduates in 21stcentury will be called upon to solve, it is imperative for the budding engineers to hone the 21 century C^5 skills i.e., Communication, Creativity and innovation, Critical thinking and problem solving, Collaboration and Career skills besides other social and life skills as mentioned in detail in the text.

Their learning must encompass 21st century skills almost as much as their technical knowledge and analytical skills. For all this to achieve, engineering education has to focus on learning not on the teaching. Educators must take a hard and impassionate look to consolidate, intensify and reformulate engineering curriculum as a whole to integrate diverse classroom (and out of classroom) techniques, like cooperative learning, active learning, visuals etc., to address the learning styles of the students. Nostalgia about past practices and paradigms must give away to new thinking that foster stronger engineering graduates engagement with their education and with their social, cultural and physical environment.

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