Invited Papers

Curricula for Societally Relevant Engineering Education

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ABSTRACT

While the primary purpose of engineering education at the bachelor's level must necessarily be to produce graduates that are well versed in applications of the principles of physical, mathematical and natural sciences for the betterment of human lives and for the purposes of engineering design, an equally important objective must also be to develop the ability to critically think, have communication skills, and be able to effectively work in multidisciplinary teams to solve societal problems.

Under the leadership of the National Board of Accreditation (NBA), India was admitted as full signatory of Washington Accord (WA) in 2014. As part of being a signatory to WA, India has made full commitment to transition into outcomes based engineering education providing the perfect opportunity to redesign the engineering curricula and making it more relevant for educating students who are better prepared for the current and future needs of the society. This paper outlines some practical steps in achieving that goal.

Keywords: Learning, Outcomes, Curriculum, Engineering Education.

INTRODUCTION

The ultimate goal for humans is to achieve a sustainable society with a high quality of life for which the essential ingredients are (a) a clean environment (b) an excellent health care system (c) safety and security (d) an excellent civil infrastructure and (e) an educated and concerned citizenry that clearly understands its responsibility. None of this is possible without a thriving and sustainable economy to pay for the quality of life. Engineers can potentially play an important role for achieving every one of the above goals and that is why it is incumbent upon engineering educators to deliver an education that will produce graduates who will eventually, within 3 to 5 years of graduation, find their nitche and contribute to the most urgent needs of the society in one or more ways either directly through their primary employment or through voluntary work. India's commitment to an outcomes based engineering education through its membership in Washington Accord opens the doors for engineering educators to revamp their curricula to respond to this challenge.

The rapidly changing global events such as climate change, terrorism, cyber terrorism, an inter-dependent global economy, ubiquitous use of internet are causing even the most developed countries whose problems are quite different from developing countries to ask hard questions about the future of higher education [1] and the future of engineering education, in particular [2,3].

INDIA'S ENGINEERING EDUCATION CHALLENGES

Engineering education in India is seen as one that leads to secure and financially rewarding careers and consequently attracts large numbers of students estimated at 1 million graduates per year from about 3500+ engineering colleges. The graduates are absorbed in positions in industry, graduate schools in engineering all over the world, in management, in banking, in software industry, in a growing manufacturing industry in India and around the world, in research laboratories and in senior engineering and non-engineering government positions. An increasing number of engineering graduates are now also finding employment in retail, hospitality industry, and in healthcare delivery. If one looks at the cadre of senior bureaucrats in the Indian government, a significant fraction of them will be found to have their first degrees in engineering. In other words, the demand for engineering graduates is strong and very diverse and a large fraction of them migrate away from engineering. The migration begins as early as their first job and continues for several years after graduation.

The engineering curricula around the world have not been designed to optimally serve the large number of graduates that migrate away from engineering or for that matter even those that remain in engineering. The analysis provided in this paper applies to more than just India but the focus here will primarily be on India where the problems are visible and accentuated because of its large size. The challenges that need attention are summarized below.

Far too many credit hours packed in four years: The engineering curricula are a mix of archaic courses that have not substantially changed in more than 50 years and courses on contemporary topics have simply been added to the curriculum without taking away anything. Consequently, the semester credits to graduate have crept up and are approaching 180 credit hours in several colleges oblivious to the fact that a reasonable load per semester is 16 semester credits which for 8 semesters add to a total of 128 credit hours. This taxes the students, who spend six to seven hours per day in classes, to the point that their learning and retention of the material is severely impaired and leaves them no time to independently think. This is totally at odds with the outcomes based education that emphasizes student learning over teaching. Students do not pay much attention to self- learning, or to homework assignments or to project work.

External examinations are not conducive to learning and for curricular innovation: External examinations for assigning grades demotivate instructors to experiment with course content, effective delivery methods and curriculum modifications. Typically, instructors teach to the syllabus and the past examinations leaving little room for any innovation. Instructor's performance is judged by the performance of the students in the external examination, encouraging very structured delivery of the course.

Far too much emphasis on basic and engineering sciences than on applications and on design: It is said that the difference between a basic scientist and an engineer is that a basic scientist seeks to understand nature and its laws and an engineer seeks to exploit that understanding to improve human lives. One can then argue that if engineering is so dependent on basic sciences, that the first two years should be dedicated to mastering concepts of Physics, Chemistry, Mathematics and Biology and then build the Engineering Science courses on top of that base. This is the old way of doing things and it does not build the proper perspectives that engineers need to develop and the curriculum does not have the room for it. There is need for new integrated math and science, math and engineering science as well as basic and engineering science courses to be developed so the science and its applications are considered concurrently.

Limited flexibility to pursue a second major/minor or an interdisciplinary specialization: Pursuing secondary interests through a minor, double major or an interdisciplinary certificate program, while very desirable, is often challenging in an engineering curriculum because of limited flexibility in the form of free electives. The curricula in Indian universities are particularly noted for lack of flexibility that must be created within the constraints of a four year program.

A weak component of courses that provide a societal context for the practice of engineering: Engineers design and manufacture machinery as well as products that make humans more productive and enable them to perform tasks that would otherwise be prohibitive such as with computers. However, insufficient attention is given to unintended consequences during the design process such as to environment and/or life cycle cost. The total life-cycle engineering involving from cradle- to- grave considerations with no negative impact on the planet's ecology and cost-effectiveness should be more of upfront topics in all curricula. Similarly, matters such as advocacy for the profession, product liability in the broadest sense, public safety, estimation of risks, etc. are seldom covered as part of the curricula and are yet very important aspects of what engineers do as part of the design process.

Insufficient emphasis on communications skills, problem solving skills, and team work: Complex technological problems demand execution through good team work requiring good communications skills, problem solving skills, and an appreciation of multidisciplinary expertise among the team members. The seed for this approach and its importance must be part of the undergraduate curriculum. This is severely lacking today in a large number of engineering colleges.

Limited opportunities for internships providing quality work experience: Good quality internship experience exposing students to real work environment and providing a context for their education is important but is not commonly found. With the large numbers of students involved in India, this is very challenging. The infrastructure is simply not there in required numbers for students to leave home or their dormitories to go far away for internships and quickly become productive. Some colleges have invited companies to create such opportunities for students on campus. More such creative solutions that consider the ground realities and work around them must be found.

Insufficient exposure to project work, service learning, entrepreneurship opportunities and research: The packed curriculum of 180+ credit hours over four years drains all the faculty and student resources available, leaving no room for creative endeavors of project work, research and service learning that are so important in achieving the desired outcomes among the graduates. This can be a substitute for internship for some students that can be just as effective in exposing students to these desired skill sets.

DESIGN OF A CURRICULUM RESPONDING TO THE MODERN NEEDS

The primary purpose of engineering education at the bachelor's level must remain to produce graduates that are well versed in applications of the principles of physical, mathematical and natural sciences for the betterment of human lives and for the purposes of engineering design However, an equally important objective must also be to develop the ability to critically think, have communication skills, and be able to effectively work in multidisciplinary teams to solve societal problems. It is also just as important to keep in mind that this should happen within the constraints of a 128 credit hour curriculum. Facilitating the achievement of student learning outcomes and achieving the previously defined Program Outcomes cannot also be compromised in any way. All this is necessary to ensure that engineering graduates remain productive and in high demand for 50 years because that is how long young people are expected to work after graduation. Is this an over-constrained problem? Not, according to this author but it is one that requires rethinking and a commitment to make tough choices.

Learning and retention of information must also remain a high priority. To reduce pressure on students, it is better to design courses in units of 4 credit hours, a practice that minimizes the number of final examinations that the student is required to take in a short period of time. This may, however, not always be possible but should be a good goal to have during curriculum planning exercises.

Figure 1 shows the pyramid of engineering education with the bachelor's level at the base continuing to the master's and doctoral levels. Some students will stop at the bachelor's level and these students must be well prepared for continuing further education in engineering but also for pursuing careers in other fields. Those aspiring for a career in engineering should be advised to seek a master's level education with the possibility of earning it in one year by integrating it with the bachelor's degree such as choosing project work that will continue on for an additional year beyond the completion of the bachelor's requirement. Also, the master's level course work should be more about depth than about breadth which is vitally important at the bachelor's level.

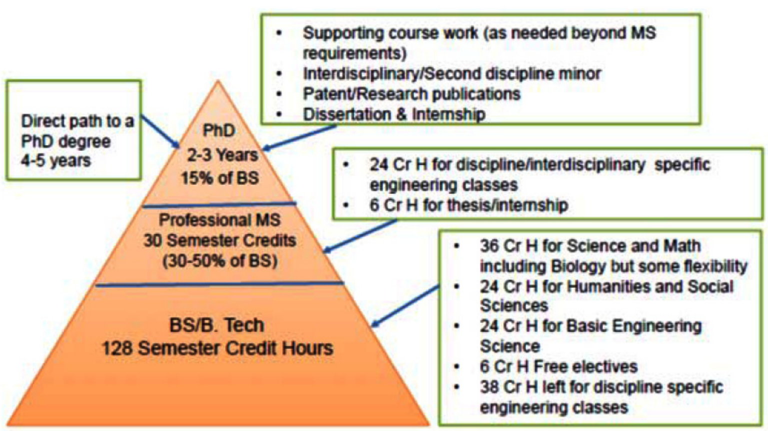

Fig. 1: Engineering Education Pyramid from the Bachelor's to Doctoral Level Education

In the subsequent discussion, we will concentrate just on the various elements of a curriculum at the bachelor's level in the backdrop of the assumption that to function as an engineering professional at a high level, a master's level education is highly desirable and this additional engineering education is unnecessary for students who will migrate into other fields.

The 128 credit hours for the bachelor's curriculum is divided into the following elements, also see Figure 1.

- 36 hours of integrated courses in Math and Science that include 16 credit hours (4 courses) of Mathematics, rigorous but survey type courses in physics, chemistry and biology (4 credit hours x 3 courses) also full of examples of applications followed by two in-depth courses in one of the sciences or mathematics such as discrete mathematics for computer science and industrial engineering majors, physics for electrical, aerospace and mechanical engineers, chemistry (physical and organic chemistry) for chemical engineers. Materials science and engineering majors can opt for a second courses both in physics and chemistry and the biomedical engineers can pursue more biology. The topics in physics courses may be tailored for electrical, aerospace and mechanical engineers differently to achieve the integration of science and engineering as discussed below.
- The 24 credit hours dedicated to humanities and social sciences (HSS) can be divided into 8 credit hours for language and literature (English or an Indian language or a combination of both), one 4 credit hour course in sociology, psychology and economics and the remaining 4 hours dedicated to advanced courses in any humanities or social science courses as HSS electives. The sociology course should include a module in human values and ethics. These 24 credits should be sprinkled over 6 of the 8 semesters and it is very important that the learning outcomes of each course be defined to support the Program Outcomes of the degree program and both HSS faculty and engineering faculty be involved in selecting the course contents.
- The 24 credit hours of basic engineering science courses must include several of the following in units of 4 credit hour courses: electrical circuits, computer programming and data structures, mechanics of solids, statics and dynamics, introduction to materials science and engineering, thermodynamics, fluid mechanics, mass and heat transfer, introduction to engineering design, introduction to biomedical engineering, introduction to nanotechnology, environmental sciences, and other discipline specific introductory courses. These 24 credit hours can be somewhat different for different majors. Also, courses such as electrical circuitry, thermodynamics, fluid mechanics etc. can be taught in several discipline specific versions. Ideally, half of the above courses can be common and the second half can be different using examples from the various disciplines.
- The 6 hours of free electives can be used to pursue secondary interests in other fields of engineering, or to go deeper into HSS, business management, IT, basic science fields, or gain service learning experience, research experience, etc. Alternatively, students can be involved in organized entrepreneurial activities around new businesses by learning to build business plans.
- 38 credit hours of discipline specific courses must include 6 credit hours of capstone design sequence over two successive semesters, 6 hours of engineering electives at the upper division level (3rd or 4th year level) within the program to gain in-depth knowledge in one topic within the major, and 24 hours of other discipline specific courses that cover the field, preferably in units of 4 credit hours to reduce the number of actual courses.
- Co-curricular program with no academic credits can be offered on the side to strengthen communications skills, leadership skills, public speaking, team work, societal service, entrepreneurial activities and various academic and non-academic clubs.

There are plenty of online open access material available to support such a curriculum, should a college commit to total revision of their engineering curricula.

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Dr. Ashok Saxena is a Distinguished Professor, a nationally recognized engineer, former dean, vice chancellor of a new university in India and the founding chair of the Biomedical Engineering Department. At the University of Arkansas he has held the 21st Century Graduate Research Endowed Chair in Materials Science (2003–2007), Irma and Raymond Giffels' Endowed Chair in Engineering (2007–2012), and the George and Boyce Billingsley Endowed Chair (2014–2015). Dr. Saxena has a long and distinguished career in academia. As a researcher, Dr. Saxena has primarily worked in the multidisciplinary fields of linear and nonlinear fracture mechanics within the disciplines of mechanical engineering and materials science. His interests over the past few years also include biomedical engineering. Dr. Saxena served as dean of the College of Engineering at the University of Arkansas from 2003 until 2012 when he stepped down to serve a two-year appointment as the senior leader at Galgotias University, a new private, multidisciplinary research university near Delhi, India. As vice chancellor (the equivalent of the campus CEO in Indian/British higher education) of Galgotias University, Dr. Saxena oversaw the institution's growth from zero to 6,500 students. He also helped India gain admission to the Washington Accord, a consortium of international engineering accreditation organizations.

Dr. Saxena's awards and recognition include the George Irwin Medal (1992) from the American Society for Testing and Materials (ASTM) for his pioneering contributions to creep fracture mechanics, the ASTM Award of Merit and Fellow (1994), Fellow of ASM Award (1996), and the Georgia Tech Outstanding Research Author Award (1993). He was a recipient of the Wohler Fatigue Medal from the European Structural Integrity Society (ESIS) in 2010. He is the author, co-author or editor of eight books and over 200 research publications. Dr. Saxena received his B.S. in mechanical engineering from the Indian Institute of Technology in Kanpur and his master's and doctoral degrees in materials science and metallurgical engineering from the University of Cincinnati. His major industrial experience was at the Westinghouse Research and Development Center in Pittsburgh, where he served from 1976 to 1985 and rose to the rank of Fellow Scientist. Prior to coming to the University of Arkansas, he was chair of the School of Materials Science and Engineering at Georgia Tech and was named Regents' Professor in 2002.