Engineering Curriculum Reforms to Meet Modern Challenges

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Abstract *¾ The National University of Singapore (NUS), which graduates over 1500 engineers annually, is constantly reforming its undergraduate engineering programs. The desired objective of these changes is to graduate engineers who not only possess the traditional attributes of problem-solving, analytical, communication, interpersonal, management and decision-making skills but also the modern attributes to enable them to practice their profession with competence and confidence in the ever changing world. This paper highlights the many new and innovative changes to NUS's engineering curriculum and the special programs that are available to NUS's engineering students. Besides a major curriculum reform that includes incorporation of general education subjects that promote inquiry and a "thirst" for knowledge, and key computer science subjects that are essential for engineers, NUS`s engineering curriculum also provides special programs that enable students to innovate, carry out research with high technology companies, start a company, and more.*

Index Terms ¾ Engineering Education, Curriculum Reforms, National University of Singapore.

INTRODUCTION

Singapore, an island of about 650 *sq km* and without any natural resources, has to primarily rely on its small population of about 4 million people for economic survival. Since its independence in the mid 1960s, Singapore has adopted a global outlook relying on trade, high value-added manufacturing, and services for its economic survival.

Singapore has consistently invested heavily in developing its most precious resource, its people. Singapore has been allocating 3.5% of its Gross Domestic Product (GDP) on education with plans to increase it to 4.5% of the country's GDP in the next few years. Engineering is considered as the most important discipline to drive Singapore's economy. It is not surprising that the number of engineers and technicians produced by Singapore's two universities, National University of Singapore (NUS) and Nanyang Technological University, and the four polytechnics are increasing yearly [1]. Also the quality of engineering graduates has been increasingly emphasized. The latter demand calls for better faculty members, better curriculum, better facilitation/teaching process and better educational facilities.

The engineering curriculum in the National University of Singapore (NUS) is constantly reviewed and updated to keep abreast with the technological changes and the thrust in the Singapore's economy. In this paper, we present our new modern and broad-based engineering curriculum, which will help graduates develop the capabilities and values necessary for the twenty-first century.

THE FACULTY OF ENGINEERING, NUS

The Faculty of Engineering is one of the largest faculties in the University with over 5,500 undergraduates and 300 faculty members. Its mission is "*to be the premier institution providing quality engineering education and leadership in research, development and application of technology for the advancement and well-being of the nation*". The Faculty has invested heavily in its teaching and research facilities and gives its undergraduates access to laboratories that are equipped with state-of-the-art equipment and technologies.

Faculty Members

Stringent criteria have been set to ensure the hiring of top quality faculty members [1] who are adequately qualified in the strategic areas of expertise, and forward-looking and versatile enough to accommodate changes that lay ahead. Measurable parameters are identified and conveyed to faculty members. For example, in the assessment of research, factors that will be taken into consideration include significant publications in books, journals, conference proceedings, and other scholarly outlets; peer-reviewed funding and impactful improvements or innovations in professional practice. Publications will be assessed according to objective measures of impact such as adoption, citations, awards, reviews, reputation of journals and stature of publishers. A more rational assessment of the quality of teaching has also been worked out [2]–[4]. Quality rather than the quantity of work will be the overriding factor for promotion and tenure.

IT Infrastructure

The Faculty of Engineering has state-of-the-art smart classrooms and smart lecture theatres equipped with the latest videoconferencing equipment that support its many distance-learning activities. The programs that use these facilities include:

- The NUS Singapore-Massachusetts Institute of Technology (MIT) Alliance Program
- NUS - Georgia Institute of Technology Special Term program

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- Programs with Technische Universiteit Eindhoven (TU/e) and other leading universities.

The ***Integrated Virtual Learning Environment*** [5] (IVLE) manages and supports teaching, learning and courseware management over the Internet. IVLE facilitates the organization of course materials on the web and provides a wide variety of tools and resources. IVLE provides tools for discussion forums, online chat, auto marked quizzes, class distribution lists, electronic mail, course FAQ builders, lesson plans, automatic index generation, staff homepages, course calendar, subscription services, assignment repositories, templates and much more which enrich and broaden the students' learning experience. IVLE permits students to access up-to-date course materials anytime and anywhere. IVLE also enables instructors to expand the range of materials they can make available to students, enhance communications, save time for themselves and their assistants, and help students to better prepare for class.

The campus network is an advanced high-speed Gigabit Ethernet Switching network that links all the IT resources on campus, interconnecting 104 departments in 90 buildings covering an area of 150 hectares and serving 30,000 students, and 5000 academic, research and administrative staff. The advanced network supports multimedia services such as video-conferencing, Network TV, full motion Video-on-Demand, live network chat and high volume data transfer services. NUS lectures can be webcast 'live', synchronized with presentation materials or lecture notes.

ENGINEERING PROGRAMS

In addition to graduate programs leading to Masters and Ph.D. degrees, the NUS Faculty of Engineering conducts full-time courses of study leading to the degrees of Bachelor of Engineering in the following fields: *Bioengineering*, *Chemical Engineering*, *Civil Engineering*, *Computer Engineering*, *Electrical Engineering*, *Environmental Engineering*, *Industrial and Systems Engineering*, and *Mechanical Engineering*. With the exception of the Industrial & Systems Engineering program, which was introduced in 2001, and the Bioengineering program, which is launched this year, all full-time engineering programs are fully accredited by relevant UK based professional accreditation agencies.

With the exception of students admitted to Chemical, Environmental and Computer Engineering programs, students follow the same course of study in the first year, after which they are streamed according to their academic performance and choice to complete the engineering course in one of the following disciplines: Bioengineering, Civil Engineering, Electrical Engineering, Industrial and Systems Engineering, and Mechanical Engineering.

THE NEW ENGINEERING CURRICULUM

The NUS engineering curriculum has been constantly evolving. The desired objective of these changes is to graduate engineers who not only possess the traditional attributes of good problem-solving, analytical, interpersonal, communication, management and decision-making skills but also the modern attributes that enable them to practice their profession with competence and confidence in the ever changing world. These modern attributes include learnability (ability to learn on one's own), a yearning for life-long learning, innovativeness and creativity, ability to muster knowledge from various disciplines, to employ IT, to work at the interfaces between traditional disciplines, to work in a team and to possess an international outlook [6].

The new engineering undergraduate curriculum is based on a standard curriculum structure adopted by the University. In the new engineering undergraduate curriculum, students must achieve a minimum of 160 Modular credits (MCs) to graduate. The computation of MCs includes student preparation time. Based on a student workload of 50 hours a week for 13 weeks, a typical NUS student needs to obtain an average of 20 MCs a semester which workouts out to 160 MCs for a four-year academic program.

The new curriculum emphasizes a broad-based education as evident from its structure (Figure 1), which is based on three types of requirements, namely, the *University Requirements*, *Unrestricted Elective Modules* and *Program Requirements*.

The University Requirements account for 17.5% of the total MC requirement and consist of modules that broaden the students' intellectual horizons, develop critical and creative thinking skills for independent learning, and promote spoken and written articulacy. The University Requirements consists of:

(a) ***General Education Modules*** (GEMs) that inculcate higher order qualities of the mind and intellect that make a person educated, as opposed to the practical know-how and abilities that might be useful in one's daily life or contribute to success in career. There are two types of GEMs, namely *Information and Knowledge Content* and *Knowledge & Modes of Inquiry*. The former type emphasizes on intellectual broadening while the latter on critical and creative thinking. The engineering students have to take a minimum of one GEM of each type.

(b) A ***Singapore Studies Module***, which teaches about the history of Singapore and South-East Asia. Available modules include "*A History of Nation-Building in Singapore*" and "*Singapore: Dynamics of a Global City-State*".

(c) ***Breadth Modules*** that provide students with the freedom to read subjects outside their program.

The Unrestricted Elective Modules (UEMs), which account for 7.5% of the total MC requirement, enable students to pursue their academic interests and aspirations without any restrictions. Students may make use of the UEMs to satisfy partially or wholly other *special programs* (discussed below) such as the Enhancement Program, Minor Programs, Double-Degree Program, and the NUS/Silicon Valley Program. As long as the appropriate pre-requisites are met, students can satisfy the Breadth Requirements by taking modules from any Department/Faculty, at any level.

The Program Requirements, which account for 75% of the total MC requirement, consists of modules that enhance the depth in a degree program. It consists of *Faculty (School) Requirements* (6.25% of the total MC requirement), and *Major Requirements* (about 68.75% of the total MC requirement). The Faculty Requirements consist of the following modules: *Critical Thinking and Writing*, *Engineering Professionalism*, and a Human Resource Management module. The Major Requirements consists of a set of modules that define the core knowledge and abilities expected of every student majoring in the discipline, regardless of their specialization within the discipline. The Major Requirements consist of: (*i*) science, mathematics and computing modules that are common to various engineering disciplines; (*ii*) two basic engineering modules; and (*iii*) engineering modules that form the core, breadth and depth of an engineering discipline.

For double-Major and double-Degree programs, students are required to concurrently satisfy the Major Requirements of two disciplines offered by the respective departments and faculties/schools.

SPECIAL PROGRAMS

Students can take the special programs discussed below to satisfy the UEM requirements.

Undergraduate Research Opportunities Program

The Undergraduate Research Opportunities Program (UROP) provides an opportunity for undergraduate students to do research. UROP enable students to acquire skills involved in the intellectual process of inquiry, enhance their knowledge of the latest technology and interact with faculty members. Students are expected to work on the UROP project for at least 65 hours, which may be spread over two semesters. At the end of the project, UROP students have to submit a short report. To satisfactorily complete the UROP, students must complete a literature survey on the research and must be able to:

- define the problem clearly and propose a hypothesis or a model for the problem,
- design a solution procedure/experiment to study the hypothesis or analyze the problem,
- obtain data and evidence to support the hypothesis,
- draw conclusions and make suggestions for future studies.

Minor Programs

A Minor Program is a coherent course of study providing significant depth in a certain area outside the student's chosen major. A Minor Program should be at least 24 MCs of which up to 12 MCs can be used to satisfy the UEM requirements. Double counting of up to 8 MCs from the major requirements can be granted where there exists a substantial equivalence in the modules. The following Minor programs are offered to our students:

(a) ***Minor in Management of Information Technology***

The impact of Information Technology (IT) is felt in the design, development, manufacture and marketing of products. IT is also embedded in products and services. It is vital that this key resource is efficiently managed. The aim of this Minor is to introduce students to the key concepts involved in the management of IT. The course would benefit would-be managers, engineers and entrepreneurs.

(b) ***Minor in Bioengineering***

Bioengineering is a discipline that advances knowledge in engineering, biology, and medicine. It improves human health through interdisciplinary integration of the engineering sciences with the biomedical sciences. The aim of this minor is to enable students to understand how the principles and tools of traditional engineering fields, such as mechanical, materials, electrical, and chemical engineering, can be applied in biology and medicine. This Minor will suit students who wish to pursue further career opportunities in health care, biomedical, biotechnology, biomaterials and pharmaceutical industries.

(c) ***Minor in Urban Environmental Engineering***

Asia is undergoing massive industrial and infrastructure developments and this is expected to continue for the foreseeable future. The massive developments coupled with the large and growing population will inevitably impose a tremendous pressure on the environment. The challenge is to harness technology to overcome undesirable environmental consequences and allow for continued economic and infrastructure development. This aim of this Minor is to provide a broad-based education in urban related environmental science and technology to train would-be environmental engineers who will undertake important and challenging tasks in protecting the environment and facilitating the infrastructure development on an environmentally friendly and sustainable platform.

(d) ***Minor in Technopreneurship***

The Minor in Technopreneurship aims to encourage and develop the potential of the Engineering undergraduates in starting up a technology-based business. The education will complement the technical knowledge received, by exposing students to approaches for exploiting the technical knowledge that they receive. This will enhance their contributions by equipping them with the knowledge of processes and mechanisms by which new ideas can be commercialized.

Enhancement Programs

The aim of the Enhancement Programs is to allow for broadening our students' education. These programs can be taken to satisfy the UEM requirement. To encourage students to do a variety of programs, they can only take each program once. The following Enhancement Programs are offered to our students:

(a) ***Industrial Attachment Program***

The Industrial Attachment (IA) Program is designed to:

- enable students to translate theories into solutions in the real world environment,
- instill in students the right kind of work attitude and professionalism through interaction with people in organizations and observation of their future roles in industry
- enable students to learn more than what is taught in class,
- enable students to acquire intangible attributes such as working in a team, and use of IT in the workplace.

IA enables companies to assess our engineering students, as well as to participate fully as partners in cooperative education. Students are allowed to spend a semester in industry, either in a local or overseas company. Students will only be sent to selected companies that have a good track record or have great potential in providing them with excellent industrial or research programs. Our students are strongly encouraged to go overseas to benefit from cross-cultural exposure, which is invaluable and will instill in them, a more global perspective. Students will have to submit progress reports and a final report for assessment at the end of the attachment. On successful completion of the IA, students will be awarded 12 MCs.

(b) ***Vacation Internship Program***

The Vacation Internship Program has the same objectives as Industrial Attachment Program, except that it is of a shorter duration. Students may choose to do a 10-week internship during the vacation period with companies, research laboratories or research institutions. Students will have to submit a progress report and a final report for assessment at the end of the attachment. Their performance will be closely monitored. Students who have met the requirements of the vacation internship will be awarded 4 MCs.

(c) ***Technopreneurship & Incubation Program***

The main objectives of the Technopreneurship & Incubation Program (TIP) are to:

- enthuse & prepare students, through classroom tuition and experiential learning, for a career in technology-based entrepreneurship,
- educate students on how to start up and incubate companies,
- provide the necessary resources for students to "incubate" their ideas.
- assist students to link up with companies/contacts that may be useful to their business ideas.

The TIP comprises three parts and MCs are assigned to the successful completion of each part. These MCs, (up to a maximum of 8 MCs) may be used to count towards the Minor in Technopreneurship in lieu of other approved modules, or towards the UEM requirements.

(d) ***Innovation Program***

Students taking part in the Innovation Program (IP) are engaged in semester long "hands-on" activities to create a novel outcome of practical significance. By taking part in the program, the students are expected to learn that there are significant merits and strengths in existing engineering schemes, procedures and practice, and at the same time, that these can be successfully challenged. Working sessions, talks and seminars are organized throughout the duration of the program to make students aware of problem definition, ideas generation methods and solutions, actions to be taken, barriers to creativity, method of irritation, critical evaluation, problem analysis, intellectual property protection and commercialization of ideas and products. At the end of the program, the students are expected to produce a prototype or a demonstrable system and to make a presentation to convince others of the value of the proposed idea, procedure or device. Peers will contribute to the evaluation of the success of the idea and product generated. Mentors will monitor the progress, assist in project development, and assess the student's performance. On successful completion, students will be awarded 2 MCs, which may be used to satisfy the UEM requirements.

The NUS-Georgia Tech Special Term Program

This program offers students a unique cross-cultural educational experience. The courses in this program involve participation of faculty members and students from both NUS and the Georgia Institute of Technology. The central theme of the program is Logistics and Supply Chain complemented with a historical coverage of Asia in the modern world. Singapore and Hong Kong, owing to their

excellent logistics infrastructure and standing as international hubs have been identified as optimal locations to conduct the program. The 10-week program is conducted from May to July of which six weeks will be hosted in Singapore, and the remaining four weeks in Hong Kong. Students participate in several site visits and program sponsored field trips.

Student Exchange Program

Studying abroad helps to develop cultural understanding and personal development that cannot easily be acquired through coursework alone. The international experience is a valuable asset, particularly in the open and global economic setting of Singapore. NUS has entered into exchange partnerships with selected prestigious universities around the world. The student exchange program allows students to experience and develop an appreciation of different cultures; provide an exposure to different geographical environments; and to network and establish friendly relationships. Students are selected for the program during their second year of study and embark on the exchange in the third year of study.

NUS/Silicon Valley Program

The NUS College in Silicon Valley aims to cultivate dynamic and resourceful entrepreneurs by immersing a select group of students in the dynamic technopreneurial and academic environment in Silicon Valley. Our students participating in this program will be selected on the basis of their academic ability and entrepreneurial drive. They will spend one year in Silicon Valley to intern in start-ups while taking entrepreneurship and discipline-based courses at Stanford University and other institutions in Silicon Valley. At the end of the five-year program, these engineering students will be conferred the Bachelor in Engineering with a Minor in Technopreneurship, and Master's degree.

Double Degree Program with French Grandes Écoles

The Faculty of Engineering has established Double Degree programs with the following French Grandes Écoles: École Polytechnique (X), École Centrale Paris (ECP), École Supérieure d'Electricité (Supélec), École Nationale des Ponts et Chaussées (ENPC), École Nationale Supérieure des Mines de Paris (ENSMP) and Groupe des Écoles des Télécommunications. Only the best students are eligible to apply for the program. Those who receive provisional admission will be enrolled in language classes in Singapore and involved in language immersion programs in France. They will then sit for an entrance examination at École Polytechnique and attend a confirmation interview before receiving full admission.

Students in the program undergo five years of study: first two years at undergraduate level at NUS, next two years at undergraduate level at a French institution, and the last year working towards the Master of Engineering at NUS. In the first year, students take modules to satisfy the University and Faculty requirements. They will also take special/additional Mathematics and Physics classes. During the vacation after the first year, they will spend four weeks on the language and cultural immersion in France. Besides taking second year modules in accordance with the chosen discipline, students will 130 hours of French classes at NUS and undergo another 6-week immersion in France during the vacation periods. In Years 3 and 4, students will be involved in the undergraduate engineering studies at the selected French Grande École. Upon return from France, the students will work on the Master of Engineering at NUS. Upon successful completion of the entire program, students will be conferred the Bachelor and Master of Engineering from NUS, and the Diplôme d'Ingénieur.

CONCLUDING REMARKS

The new Engineering curriculum for academic year 2002 is a result of years of reform and a new curriculum structure adopted by the University. Many elements of the curriculum have been in place for sometime and "fine-tuned" over the years based on inputs from faculty members and feedback from students and employers.

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University Requirements	Program Requirements		Unrestricted Elective Modules
4 General Education Modules = 16 MCs 1 Singapore Studies module = 4 MCs 2 Breadth Electives outside student's faculty = 8 MCs	**Faculty Requirements**: Common Year 1 module: Critical Thinking and Writing = 4 MCs Common Non Year 1 modules: Human Resource Management and Engineering Professionalism = 6 MCs	**Major Requirements**: *Common Year 1 modules* Physics IE & IIE, Mathematics I & II, Programming Methodology, Statics & Mechanics of Materials, Electrical Engineering 84 MCs for discipline-specific majors, i.e., Bioengineering Chemical Engineering Civil Engineering Computer Engineering Electrical Engineering Environmental Engineering Industrial & Systems Engineering Mechanical Engineering	12 MCs of Unrestricted Elective Modules (UEMs)
Sub-Total = 28 MCs (17.5%)	**Sub-Total = 10 MCs (6.25%)**	**Sub-Total = 110 MCs (68.75%)**	**Sub-Total = 12 MCs (7.5%)**
Total = 160 MCs			

FIGURE. 1
The structure of the NUS Bachelor of Engineering Degree