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Bioengineering Education @ NUS: A Design-Centered Curriculum

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Abstract— **In resonance with the NUS Mission, the aim of the Bioengineering undergraduate degree program is to produce engineers with a strong foundation in the relevant engineering, sciences and technology, who are able to contribute to the biomedical sciences through innovation, enterprise and leadership. Our educational program in Bioengineering is characterised by a strong emphasis on scientific and engineering fundamentals and a high degree of flexibility which can provide a wide diversity of educational experiences. By providing graduates with a combination of broad-based fundamentals and specialized knowledge, the Bioengineering program strives to graduate versatile engineers who would be best positioned to lead and be an integral part of the Bioengineering industries in the future. This paper describes the bioengineering program, both at undergraduate and postgraduate levels in the Division of Bioengineering at Faculty of Engineering in National University of Singapore.**

I. Introduction

Bioengineering is a discipline in which the principles and tools of traditional engineering disciplines are applied to the analysis and solution of problems in biology and medicine. It differs from other branches of engineering in that there is no particular subject matter or set of techniques that belong exclusively to bioengineering. Bioengineering education aims to train engineers who can analyze a problem from both engineering and a biological perspective; they should be able to anticipate the special difficulties in working with living systems and evaluate a wider range of possible approaches to solutions.

In resonance with the NUS Mission, the aim of the Bioengineering undergraduate degree program is to produce engineers with a strong foundation in the relevant engineering, sciences and technology, who are able to contribute to the biomedical sciences through innovation, enterprise and leadership. Our educational program in Bioengineering is characterised by a strong emphasis on scientific and engineering fundamentals and a high degree of flexibility which can provide a wide diversity of educational experiences. By providing graduates with a combination of broad-based fundamentals and specialized knowledge, the Bioengineering program strives to graduate versatile engineers who would be best positioned to lead and be an integral part of the Bioengineering industries in the future.

This paper describes the bioengineering program, both at undergraduate and postgraduate levels in the Division of Bioengineering at Faculty of Engineering in National University of Singapore.

II. Overview of the Bioengineering Undergraduate Education

At the undergraduate level, the Division of Bioengineering offers a four-year engineering curriculum leading to a Bachelor of Engineering degree in Bioengineering. Table 1 gives an overview of the curriculum structure for our undergraduate program. Design-based and research-based projects are an integral part of the curriculum. They help to develop the spirit of innovation and inquiry, integrative skills, and critical thinking skills in the students. Table 2 gives the detailed curriculum for the Major in Bioengineering. As can be seen, a portion of the curriculum is also set aside for non-engineering modules in areas such as engineering professionalism and human relations. These are intended to equip our graduates with the knowledge to function effectively in tomorrow's workplace. Technical electives within the curriculum allow our students to explore areas of special interest which they do in their upper years. Students may choose to specialise in one of the following areas, namely (a) biomaterials/ tissue engineering, (b) biomechanics and (c) biomedical electronics and imaging. The students may use the 18 MCs of unrestricted electives to pursue some enhancement programs viz the Industrial Attachment Program, the Vacation Internship Program or the Technopreneurship & Incubation Program. Students may also embark on Special Programs like the NUS Overseas Colleges (in Silicon Valley and Bio Valley, USA and Shanghai) for up to one-year internship with company to encourage entrepreneurship **or** the Student Exchange Program which provides them the opportunity to study in prestigious overseas universities to experience a new culture and forge friendship with foreign students.

III. Overview of the Bioengineering Postgraduate Education

The aims of our graduate program are to train graduates with:

- Core knowledge and understanding in engineering principles and concepts and their integration and application to biology and medicine.
- Basic analytical skills and multidisciplinary approach to solving bioengineering problems.
- Ability to carry out research projects independently.
- Critical thinking in fundamental biomedical sciences and technologies.

The graduate degrees offered in the Division of Bioengineering are (a) Master of Engineering (MEng) and (b) Doctor of Philosophy (PhD). Table 3 gives an overview of the admission requirements into our graduate program and the graduation requirements.

IV. DESIGN-CENTERED CURRICULUM

In the current Bioengineering curriculum, the students required to do two compulsory design modules: BN2203-Introduction to Bioengineering Design in Year 2 and BN3101-Biomedical Engineering Design in Year 3. However, in their freshmen year, the students are given the option to read a module on Engineering by Design – Biomimetic Principles in Engineering Design

The main objective of the Freshmen course on **Biomimetic Principles in Engineering Design** is to give students a hands-on introduction to bioengineering design and to gain an understanding of how biomimetic principles can be used to address engineering problems. Students will discover how one can mimic nature/biology to provide solutions to bioengineering problems. The course has a large practical component as students are presented with a bioengineering design problem and subsequently produce a solution incorporating biomimetic concepts. Novel solutions are encouraged as students are exposed to the design process from the concept stage through to the fabrication of a prototype. Some of the topics covered in this module are:

- Introduction to the design process
- Nature as a designer
- Practical biomimetics; e.g.,
  - Velcro
  - Sensing and Responding
  - Solar Transformation
  - How Humans Move Objects
- Representation of 3D objects
- Rapid prototyping basics

The lectures will provide the background information of the projects which are done in groups. Practical laboratory sessions are conducted in-lieu of lectures. The students are also introduced to computer-aided engineering drawing and instructed in the proper use of the fabrication equipment they will use to produce their prototypes. In one project, the students are required to design a manually operating pump to mimic the function of the heart and to design a tube to minimize the backflow of the fluid due to pulsatile pumping. The schematic diagram of the flow setup is shown in Figure 1. The water in the reservoir flows downwards under gravity to mimic the ventricular filling. The students need to ensure that the manually operating pump exhibit similar characteristics of the heart's pumping action and that the fluid flows in one direction only.

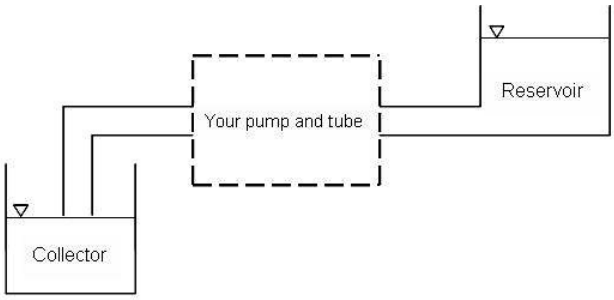

Figure 1: Schematic diagram of flow setup

The objectives of the Year 2 module on the **Introduction to Bioengineering Design** are to give the students a much better grounding in the basics skills of design as related to bioengineering, to give them more experience in performing practical hands-on design tasks, and to better prepare them for the fully fledged Year 3 design project. The topics covered in this Year 2 module are:

- Introduction to Design and Design Methodology
- Brainstorming and Design analysis
- Introduction to Design Rationale and Design Verification
- Engineering Drawing, Sketching and CAD Modelling
- Manufacturing Processes & Materials Selection for Medical Device
- Biomedical Instrumentation Design

This module introduces the students to the basic elements for design of medical devices through a hands-on design project performed in teams of about 5 students.

On completion of this Year 2 module, the students will:

- be proficient in engineering drawings and 3-D solid modelling;
- be able to design machine elements related to medical devices;
- be able to select materials for their designed products;
- have some knowledge of electronics and instrumentation related to biomedical engineering;
- have some knowledge of manufacturing processes such as injection molding and rapid prototyping;
- be able to communicate effectively and work in teams.

Examples of some of the projects undertaken by the students in their Year 2 design are:

- Mobile pulse reading device
- Vacutainer for blood collection
- Malaria detection device

- Patient specific hemodiafiltration
- Glucose measuring device

The Year 3 module on the Biomedical Engineering Design builds on the design foundation acquired in their earlier 2 years. It aims at providing the basic tools and skill sets to enable the students to develop bioengineering designs for real world medical problems requiring solutions. The topics covered in this Year 3 module are:

- Definition of Clinical Problem to be solved
- Introduction to ASTM for biomedical testing
- Quality System in Medical Device Design
- User Specifications
- Introduction to Design Rationale and Design Verification
- Intellectual Property Due Diligence
- Sterility Requirement and GMP Standards
- Introduction to Bioethics

At the end of this Year 3 module, the students will
(1) acquire skills in the design process and design documentation for medical device;
(2) know the major constrains in terms of regulatory requirements, economics, and bioethical considerations under which his or her solution will have to operate; and
(3) appreciate the clinical environment and medical needs for clinical problem requiring solutions.

Examples of some of the projects undertaken by the students in their Year 3 design are:

- Intervertebral disc implants
- Total elbow replacement implant
- Knotless bankart repair system
- Meniscal repair system

Recently a new graduate level design course has been introduced. This new design module is jointly offered by the Singapore-Stanford Biodesign Programme, the National University of Singapore and Nanyang Technological University. It leads the students through the Biodesign Process, which spans clinical needs findings and analysis; brainstorming and concept implementation; and development of business, regulatory and reimbursement strategies. The course emphasis is on the development of needs-based solutions for real medical problems. Industry veterans will be invited as guest lecturers to share real world perspectives. Students will be expected to put theory into practice by delivering a prototype and business plan.

The learning outcomes for this graduate module are:

- Able to understand and apply the Biodesign process to medical device development
- Able to devise basic strategies pertaining to regulatory approval, intellectual property, reimbursement and finance, in the context of medical device development

V. CONCLUDING REMARKS

Our undergraduate bioengineering program has been accredited by the Engineering Accreditation Board, Singapore which is one of the signatories of the Washington Accord. The latter is an international accreditation agreement for professional engineering academic degrees between the bodies responsible for accreditation in its signatory countries.

Table 1: Bioengineering Undergraduate Curriculum Structure

University Requirements	**Program Requirements**		**Unrestricted Electives**
• Singapore Studies Module (4 MCs) • General Education Modules (8 MCs) • Breadth Modules (outside student's Faculty) (8 MCs)	**Faculty Requirements** • Critical Thinking & Writing (4 MCs) • Human Capital in Organizations (3 MCs) • Engineering Professionalism (3 MCs)	**Major Requirements** • Foundation Requirements (27 MCs) • Maths/Science Core (16 MCs) • Bioengineering Core Modules (48 MCs) • BIE Design and Project Modules (22 MCs)[d]	18 MCs of Unrestricted Elective Modules (UEM)
Total MCs = 20 (12.4%)	Total MCs = 10 (6.2%)	Total MCs = 113 (70.2%)	Total MCs = 18 (11.2%)
Total minimum of Modular Credits (MCs) for graduation = 161			

Table 2: Detailed Curriculum for Major in Bioengineering

Foundational Engrg Modules	**Maths/Science Core**	**Bioengineering Core Modules**
CS1010E Programming Methodology EG1108 Electrical Engineering EG1109 Statics and Mechanics of Materials MA1505 Mathematics I MA1506 Mathematics II	CM1501 Organic Chemistry for Engineers LSM1401 Fundamentals of Biochemistry LSM2103 Cell Biology MA3501 Mathematical Methods in Engineering	BN2101-Principles of Bioengineering BN2201-Quantitative Physiology for Bioengineers BN2202-Introduction to Biotransport BN2401-Biosignals Processing BN3201-Introduction to Biomechanics BN3301-Introduction to Biomaterials BN3401-Biomedical Electronics & Systems BN3501- Equilibrium

PC1431 Physics IE PC1432 Physics IIE		and Kinetic Bioprocesses 4 Technical Electives **BIE Design and Project Modules** BN2203-Introduction to Bioengrg Design BN3101-Biomedical Engineering Design BN4101R-B.Eng. Dissertation

Table 3: Bioengineering Postgraduate Requirements

	Master in Engineering (MEng)	**Doctor Of Philosophy (PhD)**
Admission Requirements	Bachelor's degree with honors (at least 2nd Class Lower) or its equivalent	Bachelor's degree with honors (at least 2nd Class Upper) or its equivalent
Graduation Requirements	• obtain at least 16 MCs from the given list of modules; • obtained GPA > 3.0/5.0 in best 4 modules (or equivalent of 16 MCs); • obtained satisfactory grade in the Graduate English Course (Intermediate Level), where applicable; • obtain a satisfactory grade for Graduate Seminar module; • pass the M.Eng thesis.	• obtain at least 24 MCs from the given list of modules; • obtained GPA > 3.5/5.0 in best 6 modules (or equivalent of 24 MCs); • obtained satisfactory grade in the Graduate English Course (Intermediate and Advanced Level), where applicable; • obtain a satisfactory grade for Doctoral Seminar module; • pass the PhD thesis and Oral Examination.