Enhancing Biomedical Engineering Education Through Innovation Experience

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President-Elect, International Federation for Medical and Biological Engineering
President, Biomedical Engineering Society (Singapore)
Overview

• Singapore's Biomedical Sciences (BMS) Cluster
• The evolution of BMS over the past 20 years
  – Basic sciences to translational research
• Rise of MedTech Industry
• BME Education and Training for MedTech Manpower
• Innovation experience
The **Singapore Biomedical Sciences initiative** was launched in June 2000 to develop the Biomedical Sciences cluster as one of the key pillars of Singapore's economy.
Drug Discovery and Basic Research

- **S*Bio**
  - Genomics & small molecule technologies-based drug discovery
  - JV with Chiron

- **Novartis**
  - Dev’t of infectious disease therapies
  - Initial focus: TB, dengue

- **Lilly**
  - Systems biology research using bioinformatics

- **Paradigm Therapeutics**
  - Use in vivo functional genomics to predict clinical utility of novel drug targets
  - Focused on CNS and metabolic diseases

- **PharmaLogicals Research (PLR)**
  - Focus on Asian diseases, initially on breast cancer
  - Chugai-Biostar (Mitsui/CIEA) JV at Gleneagles Hospital

- **Merlion Pharma**
  - Natural products research for drug discovery
  - R&D in stem cell biology, protein chemistry & markers

- **ViaCell**
  - Dev’t of lipid-based gene delivery system platform to concentrate vectors, & technology for co-ordinated gene expression

- **Vanda Pharmaceuticals Inc.**
  - Commercialization of embryonic stem-cell technology
  - Owner of 6 ES cell lines eligible for federal research funds

- **Qugen**
  - Drug development company
  - Specializes in turning shelved or niche compounds into successful marketable products & finding new indications for existing products
Global Pharmaceutical and Biopharmaceutical Manufacturing

- Chemical bulk actives
- Antibiotics
- Technical Centre
- Chemical Process Devt

- Chemical bulk actives
- Steroids manufacturing
- Dry Powder Inhaler Finishing
- Chemical Process R&D Centre
- Pharmaceutical formulation Sterile Manufacturing plant

- Organic synthesis plant

- Nutritionals plant

- Chemical bulk actives
- Pharmaceutical formulation facility

- 200L Pilot mammalian cell facility
Medical Tech Manufacturing / Supply Chain Management

- Global Manufacturing Plant for Electrochemistry meters & Thermometry Products
- Global Manufacturing Centre of Competence for Needles & Syringes
- Global Manufacturing Site for Critical Care Systems
- Global Manufacturing Site For Hearing Aids
- Blood Bag & Catheter Manufacturing Plant
- Worldwide Manufacturing Plant for Critical Care & Interventional Cardiology products

- Large IV Sets Manufacturing Plant globally
- CAPD Solution Plant
- Worldwide Plant for Infusion Pumps
- Global Manufacturing Centre of Competence for Needles & Syringes
- Global Manufacturing Site for Critical Care Systems
- Global Manufacturing Plant for Contact Lens
- Global Manufacturing Plant for Thermal Cyclers & Sequence Detection System
- Global Manufacturing Plant for Contact Lens & Global Distribution Centre
- HQ for Global Sourcing, Procurement & Supply Chain Management
- Global Manufacturing Plant for Hearing Aids
- Medical Tech Manufacturing / Supply Chain Management
- CIBA Vision
- Siemens
- Applied Biosystems
- 1800CONTACTS™
- Eutech Instruments
- Baxter
- BD
- JMS
- Biosensos

NUS
Vision for MedTech

Location for Medical Technology
Innovate, Design & Engineer Solutions for Asia & Beyond

A Vibrant MedTech Cluster
35 Manufacturing Plants
8,000 workers

26 R&D Centers
500 Researchers & Engineers

29 Regional HQs
1,500 employees
JTC demonstrates its commitment in supporting the medical technology industry with the launch of MedTech Hub, and anchors its first customer with the signing of agreement with Biosensors at the launch event.

As part of JTC’s ongoing efforts to develop unique and specialised infrastructure solutions for key industrial sectors, JTC launched the MedTech Hub, Singapore’s first dedicated development for the medical technology (medtech) industry. Together with the launch, JTC revealed the plans for MedTech1, the first facility to be built at the MedTech Hub. Singapore’s medtech industry received an additional boost as Biosensors International Group signed their letter of interest on the same day, to lease 12,000 sqm of land to build a facility for the manufacturing of drug-eluting stents and other medical devices.
Output Contribution to the Manufacturing Sector (1990 & 2010)

Source: A*STAR 20th Anniversary Commemorative Publication, 2011
For the last 2 decades…

- **Gross Expenditure on R&D (GERD)** rose substantially from $571.7 million in 1990 to $6,042.8 million in 2009.
- **Business Expenditure on R&D (BERD)** grew from $309.5 million (54.1% of GERD) in 1990 to $3,724.5 million (61.6% of GERD) in 2009.

Source: A*STAR 20th Anniversary Commemorative Publication, 2011
Developing Human Capital

For the last 2 decades...
- Six-fold increase in the number of RSEs
- Seven-fold increase in the number of PhDs

Source: A*STAR 20th Anniversary Commemorative Publication, 2011
In the past 20 years...

- Strong clinical research base built through the biomedical research institutes in Singapore
- Dynamic research culture, excellent intellectual property protection and availability of funding and support for R&D
- Excellent physical infrastructure, pro-enterprise regulations and global connectivity

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1987</td>
<td>Singapore’s 1st life sciences institute (Institute of Molecular &amp; Cell Biology) opened.</td>
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<tr>
<td>1991</td>
<td>The National Science and Technology Board, later named A*STAR set up</td>
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<tr>
<td>1998</td>
<td>GlaxoSmithKline (GSK) set up Singapore’s first biomedical manufacturing plant</td>
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<td>2000</td>
<td>Biopolis, the biomedical sciences R&amp;D hub comprising officially opened</td>
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<td>2003</td>
<td>Completion of MEDTECH HUB, synergizing local &amp; international medtech manufacturers, suppliers &amp; service provider</td>
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<td>2010</td>
<td>Launch of the BMS initiative to develop the Biomedical Sciences as a economy key pillar</td>
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<td>2013</td>
<td>Government to invest $16.1 billion in R&amp;D under the Research, Innovation and Enterprise 2015 plan</td>
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Start of NUS Bioengineering Degree Program
NUS Bioengineering Education

• To produce engineers with strong foundation in relevant engineering and biosciences disciplines to contribute to the biomedicine through innovation, enterprise and leadership.

Bachelor of Engineering (BIOENGINEERING)
- A 4-Year Full-Time Accredited Engineering Program

Staying Relevant and Marketable

Department Consultative Committee

Signatory to Washington Accord
Department Consultative Committee

- Alok MISHRA, Vice President, Strategic Business Systems, Johnson & Johnson Medical Asia Pacific
- David CAPES, Director, Bioventure Centre Pte Ltd
- Vincent CHEUNG, Principal Consultant, Applied Quality System Pte Ltd
- Dr Raymond CHUA, Group Director, Health Products Regulation Group, Health Science Authority of Singapore
- Jason H HALSEY, Head of Singapore Operations, Life Technologies Holdings Pte Ltd
- Tse Yong LIM, Head, Biomedical Sciences, Economic Development Board
- Jacqueline MONTERIO, Associate Director, Regulatory Affairs, Surgical (Asia Pacific), Bausch & Lomb (S) Pte Ltd
- Jeffrey SCHMIDT, Vice-President, International R&D, Welch Allyn Singapore Pte Ltd
- Dr Jack WANG, CEO, Biosensors International Group Ltd
## Bioengineering UG Curriculum Structure

<table>
<thead>
<tr>
<th>University Level Requirements</th>
<th>Program Requirements</th>
<th>Unrestricted Electives</th>
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</thead>
<tbody>
<tr>
<td>Singapore Studies Module (4 MCs)</td>
<td>Faculty Requirements</td>
<td>18 MCs of Unrestricted Elective Modules (UEM) - can be used for Special or Enhancement Programs</td>
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<tr>
<td>General Education Modules (8 MCs)</td>
<td>Critical Thinking &amp; Writing (4 MCs)</td>
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<tr>
<td>Breadth Modules (outside student’s Faculty) (8 MCs)</td>
<td>Human Capital in Organizations (3 MCs)</td>
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<td></td>
<td>Engineering Professionalism (3 MCs)</td>
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<td></td>
<td>Bioengineering Core Modules (70 MCs)</td>
<td></td>
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<tr>
<td></td>
<td>Major Requirements</td>
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<tr>
<td></td>
<td>1st Year Science, Maths &amp; Foundational Engnr Modules (27 MCs)</td>
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</tr>
<tr>
<td></td>
<td>Maths/Science Core (16 MCs)</td>
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<td></td>
<td>Yr 2: Life Sciences Modules</td>
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<tr>
<td>Total MCs = 20 (12.4%)</td>
<td>Total MCs = 10 (6.2%)</td>
<td>Total MCs = 113 (70.2%)</td>
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<td></td>
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<tr>
<td>Total MCs = 161</td>
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### Notes:
- **ULR** represents University Level Requirements.
- **UE** represents Unrestricted Electives.
- The total MCs (Module Credits) for the curriculum is 161.
What is innovation?

• Innovation is the process and outcome of creating something new, which is also of value.
• “Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice.” Jan Fagerberg (Oslo, Norway)
• Innovation requires teamwork
• Schumpeter’s five types of innovation:
  – new products, new methods of production, new sources of supply, the exploitation of new markets and new ways to organise business.
**Strong Design Emphasis**

**Intent**: to create a real world experience by introducing real world medical problems requiring design solutions. Students are introduced to concepts, processes and frameworks for analyzing user needs, creating and documenting design solutions and defining and identifying constraints.

**BIE Design and Project Modules**
- GEM1505D Biomimetic Principles in Engineering Design
- BN2203-Introduction to Bioengrg Design
- BN3101-Biomedical Engineering Design
- BN4101R-Final Year Project

Design challenge is presented in a problem-focused modular format to enable the student to acquire new skills to solve a real world bioengineering problem drawing upon relevant knowledge acquired from other courses.
Year 3: BN3101 – Biomedical Engineering Design

Emphasis is placed on providing bioengineering design solutions within the constraints of regulatory requirements, economics and bioethical issues while at the same time appreciating the clinical environment and clinical needs in which the design solution will have to function.

Team members take on different roles:

- Design methodology (including ergonomics and human factors, CAD modelling)
- Quality systems
- Intellectual property protection
- Design validation
- Regulatory requirements
- Ethical Issues
- Marketing
- Costing

Emphasis is on teamwork, project-based learning and entrepreneurial thinking. The team-based term projects will require design process documentations and oral presentations.

This module aims at providing the basic tools and skill sets to enable the students to develop solutions for real world medical problems.

Consultation with clinicians on unmet needs
Presentations before “Board of Directors”

Most Innovative Design
Most Fundable Design
Against All Odds Award
The Prestigious Director Award
BN4101R- Final Year Project
The final year individual-based project provides the students with a focus in one of the 4 areas of research

Pre-Project Commencement Classes on:
• Research Methodology
• Ethics in BME research
• Lab Safety

Finale: “Bioengineering Showcase”
Showcase their work to Faculty and Industry
Enhancement Programs

- Design-centric curriculum (DCP)
- Vacation Internship Program (VIP)
- Student Exchange Program (SEP)
- NUS Overseas Colleges (NOC)
- Joint Summer School Program
- Exposure/Exploratory Field Trips

Possibility:
- Double degrees (Business/Economics)
- Minor in some other discipline
  - Business, Accounting, Economics
  - Pharmaceutical Sciences
  - Public Health
  - Medical Physics

Cross-Cultural and Cross-Discipline Learning Experiences

“X-Factor” in very general term means the unknown factor or the unexplainable thing which adds a certain value to that object, element or a person.
NUS Faculty of Engineering’s Design Centric Programme (DCP)

Unique features of DCP
Multi-year, multi-disciplinary projects
DCC students will undertake multi-year, multi-disciplinary projects addressing complex and coupled problems within three broad themes: Engineering in Medicine, Future Transportation Systems, and Smart, Sustainable Cities.

DCC Students will spend 3 to 3.5 years working together on these projects in teams composed of students from different engineering disciplines. Teams of mentors from diverse backgrounds will guide them.

Modules taught the DCP way
• Specially tailored enrichment programmes
• “Generational learning”
• Design Summer Program
• DCP Residential Program
<table>
<thead>
<tr>
<th>Year</th>
<th>#</th>
<th>SEP</th>
<th>NOC</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>48</td>
<td>16</td>
<td>4</td>
<td>41.70%</td>
</tr>
<tr>
<td>2008</td>
<td>61</td>
<td>16</td>
<td>4</td>
<td>32.80%</td>
</tr>
<tr>
<td>2009</td>
<td>64</td>
<td>19</td>
<td>2</td>
<td>32.80%</td>
</tr>
<tr>
<td>2010</td>
<td>81</td>
<td>30</td>
<td>10</td>
<td>50.00%</td>
</tr>
<tr>
<td>2011</td>
<td>65</td>
<td>21</td>
<td>9</td>
<td>46.15%</td>
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</tbody>
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**FRANCE**
- INPG
- INSA, Lyon
- Ecole Supérieure d'Electricité (Supélec)
- U Joseph Fourier
- Ecole Central de Paris
- GE4/ASE3 Program

**NETHERLANDS**
- Delft U of Tech
- Eindhoven U of Tech

**SWITZERLAND**
- Swiss Federal Inst of Tech, Zurich (ETH)
- Swiss Federal Inst of Tech, Lausanne

**NETLAND/NORWAY**
- U of Oulu
- Helsinki U of Tech
- Tampere U of Tech
- Norwegian U of Sci & Tech

**POLAND**
- Warsaw U of Tech

**SWEDEN**
- Linkoping U
- Royal Institute of Tech
- Chalmers U
- Lund U
- Uppsala U

**GERMANY**
- Aachen U of Tech
- Tech U Darmstadt
- U of Wuppertal
- U of Applied Sciences, Esslingen
- U of Applied Sciences, Ulm
- Tech U of Berlin
- Tech U of Munich
- U of Karlsruhe
- U of Stuttgart
- Tech U of Hamburg
- Harburg

**TAYWAN**
- National Taiwan U
- National Taiwan U of Sci & Tech

**JAPAN/KOREA**
- Keio U
- Kyoto Institute of Tech
- Kyushu U
- Tohoku U
- Tokyo Institute of Tech
- Korea Advanced Institute of Sci & Tech
- Korea U
- Seoul National U

**USA**
- Arizona State U
- Carnegie Mellon U
- Rice U
- U of Texas at Austin
- U of California
- U of Connecticut
- Caltech
- Georgia Institute of Tech
- Iowa State U
- U of Illinois at Urbana-Champaign
- U of Miami
- U of Wisconsin-Madison
- Pennsylvania State U
- Purdue U
- Texas A&M U

**INDI**
- Indian Institute of Tech

**SOUTH AFRICA**
- University of Stellenbosch

**CHINA/HONGKONG**
- Shanghai Jiaotong U
- Sichuan U
- Fudan U
- Huazhong U of Sci & Tech
- Nanjing U
- Nankai U
- Tsinghua U
- Zhejiang U
- Peking U
- U of Wuhan
- Xiamen U
- Sun Yat Sen U
- Xian Jiaotong U
- Hong Kong U of Sci & Tech
- Hong Kong Poly U
- U of Hong Kong
- City U of Hong Kong
- Chinese U of Hong Kong

**AUSTRALIA/NEW ZEALAND**
- U of Melbourne
- U of Queensland
- Australian National U
- U of Western Australia
- U of Sydney
- U of Adelaide
- Monash U
- U of Canterbury
- U of Auckland
The program targets NUS undergraduates with the academic ability and entrepreneurial drive, keen to be immersed as interns in start-ups located in leading entrepreneurial and academic hubs of the world. At the same time, they will study entrepreneurship related courses at highly prestigious partner universities. The aim is to cultivate and nurture them into enterprising, resourceful, independent self-starters and eventually blossom into successful entrepreneurs.
Education Programme that takes student from Discovery to Application:
Managing the Innovation Process

Understanding and Managing Innovation
1) Introduction to Technology & Innovation Management
2) Innovation Process (including the whole product concept & product development roadmapping)

Creating Value from Innovation
3) Marketing of High Tech Products & Innovations
4) The New Venture Creation Process

Protecting & Managing the Outcome of Innovation
5) Strategic Patent Management
Graduate Level

MSc in Biomedical Engineering

Specialization in:

a. Biomedical Innovation and Design
b. Healthcare System Engineering
c. Medical Physics

One Semester Compulsory Internship Attachment
The goal of SSB is to train the next generation of medical technology innovators for Singapore and Asia.
NUS Biodesign Class

Students:
Engineering
Medicine
Business

> One semester postgraduate bioengineering module
> Real-world industry speakers and projects
> Accelerated training of the Biodesign Process
Challenges faced in translating technology to commercial entities

• More role models for entrepreneurial activities in the medical and biomedical technology sectors
• Entrepreneurial success often too time-consuming from seeding agencies’ perspective
Cancer Cell Trap in Circulating Tumor Cells (CTCs) Analysis

Research Design
1. Efficiency of cancer cell isolation.
2. Purity of captured cells.
3. Viability of isolated cells.

Clearbridge BioMedics has successfully closed a S$9 million Series B financing
Faculty role-model in Innovation and Design

1) "Microcapsule-PCR" technology to perform millions of individual PCR reactions in parallel by using diffusion controlled microcapsules as reaction compartment.

2) "Reverse Phase Layer-by-Layer Encapsulation" technology to encapsulate water soluble microparticles and materials with the proven LbL polyelectrolyte self assembly method.

Encoding of every single bead is performed “In-situ” during manufacturing.

Dr Dieter Trau, co-founder of Ayoxxa Biosystems with Dr Andreas Schmidt

AyoxxA Biosystems has Series A financing 3 million Euros
Challenges faced in translating technology to commercial entities

- **More role models** for entrepreneurial activities in the medical and biomedical technology sectors
- **Entrepreneurial success** often too **time-consuming** from seeding agencies’ perspective
- **Regulatory bottlenecks** – **Training of RA Professionals**
  - Partnership with RAPS to offer a one-year Graduate Certificate in Medical Device Regulatory Affairs (MDRA)
RAPS- NUS Joint Graduate Certificate

- RAPS – Regulatory Affairs Professional Society
- Department of Bioengineering, NUS
- Graduate Certificate Course (One-year Program)
  - Overview of US Regulatory Pathways
  - EU, Australia
  - China, Japan, Korea, Taiwan
  - ASEAN
  - Format
    - Online Materials, Synchronous Discussion, Seminars
    - Projects – mock regulatory submission
- Launch date: January 2014
Education Programme:
Game-Changing By Disrupting Strategically

1) Disruptive Innovation: Understanding Innovator’s Dilemma and Exploiting Disruption (sustaining vs disruptive; conditions for disruption; organization disabilities; radical vs disruptive; etc)

2) Innovator’s Solutions: Turning The Dilemma Into Opportunities (job-to-be-done; new-market disruption; business model; impending DI opportunities; disruptive growth engine; etc)

3) Creating Growth Through DI & Reverse Innovation: Challenges in Leading the Change (emerging markets; game-changing in various sectors – energy, water; Reverse Innovation; new: Think Local Act Global; etc)

4) Creating Disruptive Technologies & Innovation Opportunities (R&D Strategies for developed or emerging markets; Frugal Engineering; combining with Open Innovation; IP strategies; etc)
CONCLUDING REMARKS

BMEs interfaces between the medical community and product manufacturers to improvement healthcare and medical practice. Great opportunity of innovation at the interface.
Thank you