Biomedical Opportunities in the Undergraduate EE Curriculum

ECEDHA Meeting
New Orleans, March 20, 2009

Arye Nehorai
Chair, Department of Electrical & Systems Engineering
The Eugene and Martha Lohman Professor of Electrical Engineering
www.ese.wustl.edu
Outline

• BSEE Pre-med Curriculum

• Imaging Sciences Pathway Program

• Example: ESE 489/589 Biological Imaging Technology

• Biomedical Undergraduate Research

• Bioimaging Study Abroad Program
BSEE Pre-med Curriculum
Pre-med Requirements

Two semesters of:

- Biology with lab
- Physics with lab
- General Chemistry with lab
- Organic Chemistry with lab
- Math to include differential equations

Each medical school has its own required and suggested courses listed in the “Medical School Admission Requirements,” published by the Association of American Medical Colleges (AAMC)
Students must complete a selection of courses for which the accumulated engineering topics is 45 units. Also certain restrictions apply about the total number of credits of ESE 400 (independent study) and ESE 497 (undergraduate research.)
### Pre-med Sample Plan

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth Elective</td>
<td>9</td>
</tr>
<tr>
<td>Free Electives</td>
<td>10 of 11</td>
</tr>
<tr>
<td>Non-ESE Engineering Elective</td>
<td>3</td>
</tr>
<tr>
<td>ESE 141 Intro. Robotics</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>23</strong></td>
</tr>
</tbody>
</table>

### Department of Electrical & Systems Engineering

**BSEE Curriculum**

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Semester 1</th>
<th>Semester 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 132 Calculus II</td>
<td>MATH 233 Calculus III</td>
<td></td>
</tr>
<tr>
<td>PHY 117A General Physics I</td>
<td>PHY 118A General Physics II</td>
<td></td>
</tr>
<tr>
<td>CS Elective</td>
<td>Elective Free</td>
<td></td>
</tr>
<tr>
<td>ESE 141 Intro. Robotics</td>
<td>Elective Humanities or Soc. Sciences</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year 2</th>
<th>Semester 1</th>
<th>Semester 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 217 Differential Equations</td>
<td>ESE 317 Engineering Mathematics</td>
<td>EE Elective with engineering units (3 credits)</td>
</tr>
<tr>
<td>ESE 230 Intro to Electrical Electronic Circuits (4 credits)</td>
<td>ESE 330 Electromagnetics Principles (3 credits)</td>
<td>EE Elective with engineering units (3 credits)</td>
</tr>
<tr>
<td>ESE 232 Electronic Circuits</td>
<td>ESE Laboratory ESE</td>
<td>EE Elective with engineering units (3 credits)</td>
</tr>
<tr>
<td>Elective EE Breadth</td>
<td>Elective EE Breadth</td>
<td>EE Elective with engineering units (3 credits)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year 3</th>
<th>Semester 1</th>
<th>Semester 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 260 Intro to Digital Logic (3 credits)</td>
<td>Elective EE Breadth</td>
<td>Elective EE Breadth</td>
</tr>
<tr>
<td>ESE 351 Signals and Systems (3 credits)</td>
<td>Elective Free</td>
<td>Elective Free</td>
</tr>
<tr>
<td>ESE 326 Prob and Stats for Engineers (3 credits)</td>
<td>Elective EE Breadth</td>
<td>Elective EE Breadth</td>
</tr>
<tr>
<td>ESE Elective</td>
<td>Elective Free</td>
<td>Elective Free</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year 4</th>
<th>Semester 1</th>
<th>Semester 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESE 498 Senior Design Laboratory (3 credits)</td>
<td>Elective EE Breadth</td>
<td>Elective Free</td>
</tr>
<tr>
<td>Engineering Course (3 Credits)</td>
<td>Elective EE Breadth</td>
<td>Elective Free</td>
</tr>
<tr>
<td>EE Elective with engineering units (3 credits)</td>
<td>Elective EE Breadth</td>
<td>Elective Free</td>
</tr>
</tbody>
</table>

**Pre-requisite**

- EE Elective
- H & SS Elective
- ESE Laboratory
## Pre-med Sample Plan

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 112A, Gen. Chemistry 2</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 152, Gen. Chemistry 2 Lab</td>
<td>2</td>
</tr>
<tr>
<td>BIO 2960, Principles of Biology 1</td>
<td>4</td>
</tr>
<tr>
<td>BIO 2970, Principles of Biology 2</td>
<td>4</td>
</tr>
<tr>
<td>BIO 3058, Physiological Control Systems</td>
<td>2</td>
</tr>
<tr>
<td>CHEM 251, Organic Chemistry 1</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 252, Organic Chemistry 2</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 257, Organic Chemistry Lab</td>
<td>2</td>
</tr>
<tr>
<td>Elective Humanities or Soc. Sciences</td>
<td></td>
</tr>
<tr>
<td>Elective Humanities or Soc. Sciences</td>
<td></td>
</tr>
<tr>
<td>Elective Humanities or Soc. Sciences</td>
<td></td>
</tr>
<tr>
<td>Elective Free</td>
<td></td>
</tr>
<tr>
<td>Elective Free</td>
<td></td>
</tr>
<tr>
<td>Elective Free</td>
<td></td>
</tr>
<tr>
<td>Elective Free</td>
<td></td>
</tr>
<tr>
<td>Elective Free</td>
<td></td>
</tr>
<tr>
<td>Elective Free</td>
<td></td>
</tr>
</tbody>
</table>

*Total: 23*
# BSEE Pre-med

## Course Substitutions

<table>
<thead>
<tr>
<th>EE Curriculum Flexible Courses</th>
<th>Switch to</th>
<th>Pre-med Required Courses</th>
</tr>
</thead>
</table>
| 9 units of Breadth Electives  | • 3 units CHEM 112A Gen. Chemistry 2  
|                               | • 3 units CHEM 251 Organic Chemistry 1  
|                               | • 3 units CHEM 252 Organic Chemistry 2  |
| 10 of 11 units of Free Electives | • 4 units BIO 2960 Principles of Biology 1  
|                                | • 4 units BIO 2970, Principles of Biology 2  
|                                | • 2 units of BIO 3058 Physiological Control Systems  |
| 1 unit ESE 141 Intro. Robotics  | • 2 units of CHEM 152, Gen. Chemistry 2 Lab  
| 3 units of non-ESE Engineering Electives | • 2 units of CHEM 257, Org. Chemistry Lab  |

Total Units 23
Imaging Sciences Pathway Program
Motivation

- Imaging sciences are multi-disciplinary, requiring knowledge of biology, chemistry, physics, engineering, and applied mathematics.

- Washington University has many imaging resources and experts. It is nationally ranked in the top three of NIH funding for imaging sciences research.

- Imaging Sciences Pathway emphasizes biomaging for undergraduate students in engineering, the physical and life sciences.
Imaging Sciences Pathway Goals

• Educate “renaissance scientists” whose knowledge of the physical sciences, engineering, chemistry, and biology will allow them to explore new frontiers within the various and ever-expanding research domains of imaging sciences

• Provide undergraduate students with extraordinary opportunities to carry out research with more than 60 leading investigators in the imaging sciences from more than 15 clinical, science, and engineering departments

• Provide undergraduate students in the physical and life sciences and engineering first-hand experience in this exciting area of biomedicine
Imaging Sciences Pathway Program

Consists of two parts:

- An introductory freshman/sophomore seminar introduces prospective Pathway students to the diverse imaging sciences research under way in Arts & Sciences, the School of Engineering & Applied Science, and the School of Medicine.

- Courses for juniors and seniors focus on chemistry, physics, computer science, engineering, and molecular cell biology as they relate to imaging sciences.
Imaging Sciences Pathway Curriculum

Core courses: select one from each of the following groups

1) Seminar in Imaging Sciences (BIO 1810)

2) Introduction to Cell Biology (BIO 334)
   - Principles of Biology I (BIO 2960)
   - DNA Science: A Hands-On Workshop (BIO 280)
   - Biochemistry (BIO 4501/CHEM 456)

3) Principles & Applications of Biological Imaging (BIO 5146)

4) Contrast Agents for Biological Imaging (BIO/CHEM 5147)
   - Biological Imaging Technology (ESE 489/589/BME 494)

Students completing the ISP requirements receive a **Milestone** on their transcripts
ISP Undergraduate Research

- Students choose two faculty mentors from different disciplines (e.g., engineering and biology), with one being the primary mentor.

- Junior and senior Pathway students participate in an interdisciplinary imaging research project in the lab of the primary and/or secondary mentor.

- Students can receive credit for independent research.

- Students also participate in summer research internships between their junior and senior years; stipends are available through NIH R90 funds.
 Facilities

The Pathway makes extensive use of the University’s vast imaging resources, which cover the full spectrum from molecular microscopy to full body human imaging.

- Mallinckrodt Neuroimaging Laboratories
- WU Small Animal Imaging Resource
- Cardiovascular Imaging Laboratory
- Molecular Imaging Center
- Center for Clinical Imaging Research
- Electronic Systems & Signals Research Laboratory

- High-Resolution NMR Facility
- High Throughput Screening Robotics Core
- Deep-Etch Electron Microscopy Facility
- Center for Biomedical and Bioorganic
- Mass Spectrometry
- Bakewell Neuroimaging Laboratory
Department of Electrical & Systems Engineering

BSEE Curriculum

**Imaging Sciences Pathway Plan**

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth Electives</td>
<td>9</td>
</tr>
<tr>
<td>Free Electives</td>
<td>4 of 11</td>
</tr>
<tr>
<td>EE Electives</td>
<td>3 of 15</td>
</tr>
</tbody>
</table>

Total 16
BSEE Imaging Sciences Program (Cont.)

- Students participate in imaging research projects and can receive credits under ESE 497 Undergraduate Research.
- 16 total units required for ISP with pre-requisites.
- 20 available units in traditional curriculum consisting of free and breadth electives.
## BSEE Imaging Sciences Program

### Course Substitutions

<table>
<thead>
<tr>
<th>EE Curriculum Flexible Courses</th>
<th>ISP Required + Prerequisite Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 units of Breadth Electives</td>
<td>• 3 units CHEM 112A Gen. Chemistry 2</td>
</tr>
<tr>
<td></td>
<td>• 2 units CHEM 152 Gen. Chemistry 2 Lab</td>
</tr>
<tr>
<td></td>
<td>• 4 units BIO 2960 Principles of Biology 1</td>
</tr>
<tr>
<td>4 of 11 units of Free Electives</td>
<td>• 1 unit BIO 1810 Seminar In Imaging Sciences</td>
</tr>
<tr>
<td></td>
<td>• 3 units BIO 5146 Principles and Applications of Biological Imaging</td>
</tr>
<tr>
<td>3 of 15 units of EE Electives</td>
<td>• 3 units ESE 489 Biological Imaging Technology</td>
</tr>
<tr>
<td></td>
<td>• 3 units of ESE 497 Undergraduate Research on imaging research projects</td>
</tr>
</tbody>
</table>

Total Units: 16
Example: ESE 489/589 Biological Imaging Technology
ESE 489/589 Biological Imaging Technology

- Course coordinators and modality experts:
  - J. A. O’Sullivan, ESE
  - J. P. Culver, Radiology
  - Y.-C. Tai, Radiology
  - J. Shimony, Radiology

Experts in EE, physics, biomedical physics, radiology.

- Textbook-based:
  J. L. Prince and J. M. Links,
  *Medical Imaging Signals and Systems*, Prentice-Hall, 2006

- Four lectures per modality:
  - Physics, mathematics, imaging
  - Lab tours and foundational literature critique
Biological Imaging Technology

- **Organ**
  - (e.g. CT, MRI, US)

- **Tissue**
  - (e.g. Intrinsic optical imaging of cat visual cortex)

- **Cells**
  - (e.g. fluorescence microscopy)
Lab Tours

- State-of-the art facilities in WU School of Medicine
- Example: CT and PET-CT imaging machines
- CCIR Center for Clinical Imaging Research
- Siemens equipment

SOMATOM Definition CT Scanner

Biograph 64/40: PET-CT scanner

CT (anatomical image)

Fused PET-CT

PET (functional image)

Data (PETCT-165) from R. Laforest and M. Mintun, Radiology
Contrasting state-of-the-art facilities with foundational papers

Littrature Critique


SOMATOM Definition CT Scanner
Literature Critique (Cont.)

Contrasting state-of-the-art facilities with foundational papers

Biograph 64/40: PET-CT scanner

First whole-body PET machine, designed and built at Washington University in St. Louis

E. Hoffman, M. Phelps, N. A. Mullanli, C. S. Higgins, and M. M. Ter-Pogossian, Instrumentations and Physics, 1976
Biomedical Undergraduate Research
Development of a High-Frequency Ultrasonic Imaging Platform

Amanda Virkus with R. Martin Arthur

Project: Ultrasound thermometry

Student contribution: Upgrade a 7.5 MHz pulse-echo system to work at 35 MHz

Configuration for automatic thermal image measurement from tissue samples during Hyperthermia

A 35-MHz ultrasound image of pig muscle
**Deformable Template Hearts for Electrocardiography**

John Bogovic with R. Martin Arthur

**Project:** Individualize heart models using a deformable model. Goal: compare normal with pathological electrical patterns on the same heart

**Student contribution:** Test suitability of candidate template hearts and quantify alignment errors

Visible Human heart model. Spherical harmonic approximation in red

Comparison of two deformed templates aligned at the apex of the heart
Bioimaging Study Abroad Program
Introduction to Multimodal Imaging

• **Host:** University of Tübingen MEG-Center, and the Max Planck Institute for Biological Cybernetics, Germany

• **Undergraduate students** from Electrical & Systems Engineering at Washington University will learn about medical imaging methods
Program

• May 11, 2009 – May 15, 2009

• One unit of credit, with the option to continue working on an independent study or undergraduate research course

• Lectures, projects, lab visits, and social programs

• Final report
Lectures

- The physics of SQUID sensors
- Fetal magnetoencephalography (fMEG)
- MEG for basic research and clinical application
- Application of MEG to brain machine interfaces (BCI)
- Metabolic imaging with functional MRI (fMRI) and near infrared spectroscopy (NIRS)
- BCI in fMRI
- Transcranial magnetic stimulation (TMS) as a research tool
Choose one project of:

- **Project 1**: Fetal magnetoencephalography (fMEG) and magnetocardiography (MCG)
- **Project 2**: Brain computer interface (BCI) application of MEG
- **Project 3**: Visual processing of food related pictures with functional MRI (fMRI)
- **Project 4**: Transcranial magnetic stimulation (TMS)

**Lab visits:**
- Max-Planck Institute for biological Cybernetics
- Laboratory for Preclinical Imaging and Imaging Technology of the Werner Siemens-Foundation, University Hospital Tübingen
Summary
Biomedical Opportunities in Undergraduate EE

• BSEE pre-med curriculum
• Imaging sciences pathway program
• Biomedical undergraduate research
• Bioimaging study abroad program
• Double major BSEE/BME
• BSEE/SSE curricula focused on bioelectricity, systems biology, bioinformatics, etc.
Thanks!