

Thoughts On Graduate School in Bioengineering

Prof. Bruce C. Wheeler

Part II: Masters Degrees

- Disclaimer:
- Some arguments are ... *well* ... argumentative
 - *If you are skeptical, you should ask for 2nd opinions*

Outline

- Simple rationale for BS/MS/PhD/Postdoc
- Economics of higher ed, emphasizing graduate programs
- *Making Sausage!* – *the compromises/inconsistencies, yet the whole system works well*
- *Part 1: PhD programs – previous talk*
 - *Advice on choosing a PhD program*
 - *How candidates are chosen by the university*
 - *Student support*
- **Part 2: Masters Programs – this talk**
 - Categories of MS programs -- examples
 - What you should think about in choosing one
 - What do MS programs in other majors look like?

Thoughts On Graduate School in Bioengineering

... from the 30,000 foot level ...

- Graduate Education in the USA is the best in the world
- Research is the best in the world
- The technology created drives the world's economies
- Like anything that really, really works – you have to look at "*how the sausage is made*" – economics, etc. of grad school
- Tremendous opportunities for MS / MEng students in both MEDTech and BIOTech industries

MS Degrees

- Remember ... Universities want your money ... watch out!
 - ... they offer something that you really want
- Used Car Dealer Analogy
 - ... you have to have a car ... your first big purchase
 - It's a lot of work, but you have to go to a whole bunch of dealers
 - You have to know what you want
 - Electric? 4x4? Cheap? Off-road?
 - Price point
 - In the end: you are going to buy something – be smart

This is a business proposition

(very sloppy numbers)

- As a student: tuition at \$25 K per year * 2 years = \$50k
 - Living expenses – same as if you are working
- As employee: after taxes/ living expenses? \$25k *2 =\$50k
- Net: you could be \$100k ahead by not going to grad school
- Is it worth it? Quite possibly!!! Depends on you.
- Anecdotes
 - Student who rebelled at Cornell's \$50k/yr tuition
 - My Prof told me I would lose \$1M if I pursued a PhD
(FYI – I lost \$1M but you are worth more than \$1M)

Why Do You Want an MS?

- Parents said "do it" or "we'll support you one more year"
- "I'll figure out life next year" – just stalling
- Med School
- Grad (PhD) School
- I want to design X – see later slides
- I want an engineer's job in Medtech/Biotech
- I want to create a company in Medtech/Biotech

If you want to design X ...

- Hip implants – why aren't you applying to MAE or Materials Science?
- Pacemakers, seizure stimulators -- ... apply to ECE?
- Personal monitoring devices ... ECE? Data Science? MAE?
- Next Gen Glucose Monitors ... Chem E?
- ... and a host of computer aided analysis techniques?

- See end of presentation

I want to design X for medicine ...

- I want to shadow a doc ...
- ... to understand the needs
- ... a gap
- I want to either
 - Use my knowledge to work on the design
 - Hire domain experts to build the solutions I envision
- Increasing number of programs
 - Rich ones – Stanford, Hopkins
 - State schools – UCSD, ...

Types of MS Programs in Bioengineering (and examples)

- Bridge to PhD -- UCSD MS
- Bridge to MD -- UCSD MS Med
- Bridge from non-bio Engineering – YYY University MS
- Bridge to Industry/Management
 - Design methods / soft skills, shadowing MDs (needs ...)
 - UCSD MEng...
- Global BME Solutions – Rice University
- Newly evolving Device Design
 - UCSD MEng Medical Devices
- Device design bioengineering with strong coursework
 - XXX University Medical Imaging and Computation
- Contrast: Established MS in long-established industries
 - Power Engineering

Bridge to PhD Programs

- Example: UCSD Master of Science (since ... 1990?)
 - Courses mostly from the PhD program
 - Plan I – path to PhD – MS thesis required; hence, lab required
 - Plan II – coursework plus exam, terminal degree
 - not likely to lead to PhD
 - Courses – next slide
- Most USA programs began with MS as
 - Opportunity for small numbers of UG students
 - Screening for PhD
 - “to be tolerated” –they had to have UG, but want PhD for research; their heart isn’t in MS degrees; accept a few to PhD
- You must watch out before assuming you’ll get to PhD!!!

UCSD BioE GRAD COURSES

- Critique of UCSD BioE grad courses
 - Excellent science, need evolution to engineering
- Solid coursework developed to support the PhD program
 - Significant concentrations (two to three courses in each area)
 - systems biology (computational modeling),
 - biophysics (transport, thermo),
 - biomechanics
 - biomedical (cardiovascular, neuromuscular),
 - tissue (several advanced courses),
 - imaging
 - bioinformatics
- Not focused on MedTech or BTech Industry

Bridge to MD Programs

- UCSD Master of Science Med
 - Clinical Courses BEN 294ABC in early stages
 - Patient Centered Clinical Medicine for Bioengineers (King)
 - Engineering in the Patient Healthcare System (Schmid-Schoenbein)
 - Clinical Experience in Bioengineering (Engler)
 - Other courses mostly from the PhD program
 - Will allow 3 UG biology courses
- Good for MD applicants but ... NO GUARANTEES!
 - That's not what we are offering
 - Do all your homework on courses, research + volunteer experiences
 - UCSD eliminated BS/Med major because students were less successful
 - Competence is more important than major

Bridge from Other Engineering to Bioengineering

- MS courses often duplicate upper division UG courses
 - Instrumentation, Physiology, Molecular Biology
 - Often: signals or biomechanics
- Example: YYY University – summary of MS curricula
 - Physiology, Stats, (choose one of Signals, Data Science, Modeling)
 - These are close to our and their UG senior courses
 - Electives, 2 of which are UG core; 4 are faculty specialties
 - 3 other electives from engineering or medicine
 - Clinical shadowing

Global BME

- Look to RICE – the leader in global impact of BME
- Increasingly
 - Part of UG design
 - MS design

Bridge to Engineering Management in Industry

- Coursework at moderate graduate level
- Design Project
- Substantial fraction of work is ...
 - Entrepreneurship or Business oriented
 - Often .. Introductory regulatory affairs

Example: UCSD MEng

Core Courses (take 6) provides opportunity for focus but heavily PhD courses

- Engr Physics
 - BENG 221 (Math Methods); 223 (Thermo); 226 (Biomech); 227 (Transport)
- Physiology:
 - BENG 230A (Biochem); 230B (Cell/Molecular); 230C (Cardiovascular); 230D (Respiratory); 232 (Musculoskeletal); 260 (Neurodynamics)
- Tissue Engineering and Regenerative Medicine
 - 241A (Foundations), 241B (Cell Microenvironment); 241C (Development & Growth); 242 (Polymer Sci/Engr)
- Imaging
 - 247A (Biophotonics), 280A (Imaging Principles); 280B (Comparative Imaging)

Elective Courses (take 3) – from many grad level courses from BioE, MAE, ECE

General Elective (take 3) Business Oriented

Business of Biotech, Venture Mechanics, Enterprise Dynamics, Applied Innovations, International Relations (several courses); Detection Theory; Optimization

Design Project (1 course)

Design Component as Part of BioE MS Programs

- Almost all programs require a design project
 - Mixed emphases
 - Business – needs to solutions
 - Engineering – critical engineering assessments
- Most are
 - One semester
 - Higher level than senior design
 - Less time, involvement than senior design !!??

Device Engineering MS Programs

- Characteristics
 - Assume students have major/minor in BME and a second engineering discipline
 - cross-disciplinary faculty have expertise in multiple facets of the BME/Medical area
 - Coursework highly focused on a topic
- Two Examples
 - UCSD – starting a program
 - XXX University – quickly having started a program

Example: UCSD MEng Medical Device Engineering

Newly created, coursework evolving

Core Courses – **mostly management / business oriented** (required)

- BENG 261A Clinical Perspectives in Medical Device Design
- BENG 261B/C Medical Device Experience I and II (presumably Winter/Spring practicum)
- BENG 262 Biomaterials for Medical Device Design
- BENG 224 Regulatory Affairs (Prado)
- BENG 225 Business of Biotech (Bartko)

Elective Courses (take 4) – **here you create engineering focus**

- BENG 241A Tissue Engr and Regen Med
- BENG 247A Advanced Photonics
- BENG 247B BioElectronics
- BENG 247C BioNanotechnology
- ECE 202 Medical Devices and Interfaces
- ECE 203 Biomedical Integrated Circuits and Systems
- ECE 212AN Principles of Nanoscience and Nanotechnology
- ECE 212BN Nanoelectronics
- CSE 250A/BZ Principals of AI
- Two other grad level courses from BioE, MAE, ECE

Device Engineering MS Programs

- Example: XXX University MS in Biomedical Image Computing
- Coursework – comprehensive set of advanced courses in the area
 - Biomedical Computed Imaging Systems
 - Computational Mathematics for Machine Learning and Imaging
 - Applied High-Performance Computing for Imaging Science
 - Current Topics in Biomedical Imaging
 - Statistical Analysis of Biomedical Images
 - Applied Deep Learning for Biomedical Imaging
 - Foundations of Imaging Science
 - Biomedical Image Computing Capstone Project Literature Review
 - Regulations, Ethics and Logistics in Biomedical Applications of Machine Learning
 - Deep Generative Models in Bioimaging
 - Elective from grad level CS/ECE/BioE Imaging and Instrumentation
- Biomedical Image Computing Capstone Project (Industry Sponsored)

What Does an MS Degree Look Like in a Mature Engineering Field

- Power Engineering
 - As far from your interests as possible!
- Electrical power engineering is over a century old!
- We expect that BME will offer MS programs with equal specificity in ?20 years?

- Again – this represents a mature MS Degree Offering

Power / Energy MS Degree

5 courses ECE, 1.5 courses professionalism, 10 other advanced engr/science course. Courses in Power Concentration (semester hrs)

- ECE 431, Electric Machinery (4 hrs)
- ECE 432, Advanced Electric Machinery (3 hrs)
- ECE 464, Power Electronics (3 hrs)
- ECE 469, Power Electronics Laboratory (2 hrs)
- ECE 476, Power System Analysis (3 hrs)
- ECE 530, Analysis Techniques for Large-Scale Electrical Systems (4 hrs)
- ECE 568, Modeling and Control of Electromechanical Systems (4 hrs)
- ECE 573, Power Systems Operations and Control (4 hrs)
- ECE 576, Power System Dynamics and Stability (4 hrs)
- ECE 588, Electricity Resource Planning (4 hrs)

Support for a well-developed internationally prominent industry needing many students at the MS design level. Students are well prepared as design engineers for power companies.

My opinion: Bioengineering is still emerging as an engineering discipline

- MS – level – sophistication and depth of coursework does not match the other engineering disciplines
- Some areas are still really biology
 - Tissue Engineering Immuno-Engineering
- Comment from another field:
 - Financial Engineering is business not engineering

My opinion: Bioengineering is still emerging as an engineering discipline

- In 20 to 30 years, there will be MS programs in
 - Orthopedic Engineering -- perhaps 8 courses
 - Cardiology Engineering -- ... Neural Engineering ...
- Today
 - Almost no BME MS or PhD programs with this degree of focus
- NIBIB struggles with ... for example
 - Lots of good biomechanics research with modeling, computation
 - Industry can't figure out what is important
 - No consensus for orthopedics, etc. as to what is baseline
 - No consensus for biomanufacturing, ... bioelectronics ...
 - This struggle is not present in other engineering disciplines

Maybe ...

Why Not an MS in Another Field?

Some of the obvious alternatives

- Data Science/CS – all kinds of applications
- ECE – wearables, photonics
- MAE – mechanics, devices, orthopedics (my niece*)
- ChemE – pharma manufacture
- Materials – implants, orthopedics (my daughter*)

* both successful in MedTech with BS degrees in MechE, Materials Engrg

MS in ECE at UCSD?

Several BSYS and BENG students have done this

Faculty very active in BioE are in yellow

■ Bioinstrumentation Courses

- ECE 201 Intro Biophysics
- ECE 202 Medical Devices and Interfaces
- ECE 203 Biomed Integrated Circuits and Systems
- ECE 204 Statistical Learning in Bioinformatics
- ECE 207A Principles of Medical Imaging (= ~BENG 280A)
- ECE 208 Computational Evolutionary Biology
- ECE 209 Statistical Learning for Biosignal Processing

■ Prereqs are mostly within reach for BioE majors

- Faculty: Cosman, Dayeh, Dey, Fainman, Gilja, Hall, Kuzum, Liu, Lo, Mercier, Nguyen, Rao, Rao, Siegel, Sievenpiper, Vasconcelos, Wang, Yip, Zeger

MS in MAE at UCSD?

Several BSYS and BENG students have done this

Faculty very active in BioE are in yellow

- Specialization in Biomechanics
 - 2023: degree title "Biomechanics and Biomedical Engineering"
- Bio Related Courses
 - MAE 209 Continuum Mechanics in Biology
 - MAE 262 Biological Fluid Mechanics
 - MAE 263 Experimental Methods in Cell Mechanics
 - MAE 266 Biomaterials
 - MAE 285 Design of Micro/Nano acoustic fluid devices
- Faculty – areas Biomechanics, Biomaterials, Med Devices
 - Boechler, Chen, Delsun, Friend, Lal, Kamensky, Lindsey, Meyers, Poulikakis, Rangamani, Saintillan, Sanchez, Talke, Valdez-Jasso

There are a lot of great universities

Every year I write recommendations to some of them

- Oxford, University College London
- Max Plank Institutes, Freiburg, Tech U Munich, ...
- ETH, EPFH Switzerland; Katholieke U, Belgium
- Tsinghua U, Beijing; Chinese U. Hong Kong
- Tokyo U; Kyoto
- KAIST, Seoul National
- Regionally wonderful!!!
 - Pontifical Catolica Universidad del Peru

- Many more

Simple Summary

- BME is a great and expanding area
 - The science possibilities range from obvious to unbelievable
 - The job opportunities range from ... great to disappointing
- PhDs offer entrance to the elite of our emergent technologies
- Masters offer tech-management opportunities to our emergent technologies
- Choose wisely – you can go wrong, but much more likely you will go right