The *de facto* core curriculum in BME and BioE

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One question quiz:

“Although each of the accredited undergraduate curricula evolved independently, commonalities exist among the group. There is also a desirable diversity and flexibility among the curricula.”

This statement appeared in an abstract in:

1984
1991
2003
2010
“Although each of the accredited undergraduate curricula evolved independently, **commonalities exist among the group.** There is also a desirable diversity and flexibility among the curricula.”

This statement appeared in an abstract in

1980

**1991 – 28 years ago.**

2003

2010

Probably the first indication of a core in BME:


What Eric said 28 years ago will also be my conclusion!

While no one and no organization has dictated a curriculum, or even really recommended one, there is a body of material that has become the core of most undergraduate BME programs
Abstract came from the real first BME Education summit, funded by NSF “Workshop on the Undergraduate Curricula in Bioengineering” Wright State University March 7-10, 1991

One outcome was creation of the Council of Chairs of Biomedical Engineering and Bioengineering, led initially by organizers of the workshop:

Blair Rowley, Wright State, Chair
Eric Guilbeau, Arizona State, Steering committee
Paul Hale, Louisiana Tech, Steering committee
Gerald Saidel, Case Western Reserve, Steering committee

1991 Zeroth BME Education summit
2000 First Whitaker Education summit
2005 Second Whitaker Education summit
2008 Third BME Educational summit
2019 Fourth BME Educational summit
All 19 accredited programs were at the Zeroth BME Education “summit”
Organizers were among first generation of BME faculty; mostly retired.
• Were any of you at that meeting (1991)?
• How many at first Whitaker Summit (2000)?

Now 119 accredited programs
• Approaching ChemE which has 166

Why are we talking about curriculum this week?
• Need to revisit curriculum because new people enter the field
• Curriculum might need revision
• Curriculum work is never done
Outline

Why are we interested in defining a core?
Research on two ways of defining the core
  • Courses
    • 2004, 2013, 2019
  • Concepts
Work that we might do next
Conclusions
Why worry about core biomedical engineering curriculum?

1) Defining the field of biomedical engineering
No agency has determined what all undergraduate Bio(medical) engineering students should know. Is there a core body of material? What distinguishes a BME from other engineers?

2) Marketing BME to industry
Clarifying the core would assist industry in knowing what to expect from biomedical engineers – at a minimum

• What do all BMEs know?
• What can they be expected to do?

3) What is the market for textbooks and other educational materials?
Research on the BME core curriculum

Funded by NSF from 1999 to 2008
NSF thought we should make recommendations about the ideal undergraduate BME Curriculum
  • We thought no one would pay attention
We decided instead to investigate the status of BME – to what extent is there a de facto core, even if no one recommended it?
Only comprehensive research on the BME core
Thanks to David Gatchell, postdoc at the time, now:

Director, Manufacturing and Design Engineering Program
Charles Deering McCormick Distinguished Clinical Professor
Clinical Associate Professor in Biomedical Engineering and Mechanical Engineering
Two approaches to the BME Core

Courses - What courses are required at different BME programs. Courses required at many places could be regarded as core material.

Concepts – What concepts do faculty and industry representatives regard as important for all undergraduates in BME?

Limitations:

Courses are an imperfect measure, because they don’t reveal concepts or depth.

Concepts are imperfect because they don’t reveal actual teaching.

Professional skills* are not captured. Can students communicate, make ethical judgements, use laboratory skills…?

Cognitive skills are not captured. Can students integrate concepts, transfer knowledge and problem solving skills, think critically, use models, gain adaptive expertise…

(VaNTH also did work on professional and cognitive skills.)

*Many people are trying to get away from calling these “soft skills”!
I. Investigating Required Courses

In 2004:

- Reviewed curricula of BME programs posted on university websites
- Counted *required* courses in engineering and biology
  
  Did not consider math, chemistry, physics, humanities/social science

- Generally clear what category to put a course in

  Occasionally needed to make a judgment

  Occasionally divided a course between two areas

- Counted identifiable courses, so might be undercounting

  e.g. statistics may be taught in a lab course

- Converted all curricula to semester credit hour basis

  Average curriculum = 128 credit hrs

- 40 of 43 accredited program

- 31 unaccredited programs also analyzed

In 2013:

- Revisit 16 of these programs for update

  8 accredited in the 1980’s

  8 accredited in 2007 or later

"Other" may include ethics, engineering communications or economics, etc.
Were there changes between 2004 and 2013?

16 programs evaluated in both 2004 and 2013; only minor changes
What is the core based on these data?

Taking 75% as the criterion, the 2004 core included:

- Freshman engineering
- BME Design
- Physiology
- Mechanics
- Additional Biology
- Circuits
- Instrumentation
- Computing
- Statistics
- Materials

Between 60 - 75% of programs:

- Transport
- Thermodynamics
- Signal Analysis

Less consistency in unaccredited programs in the 2004 sample. See ASEE paper.
Self-reported data obtained for this conference (n=59)

Comparison between 2004 and 2019

- Physiology
- Mechanics
- Other biology
- Circuits/Instrumentation
- Computing
- Materials
- Statistics
- Transport
- Signal analysis
- Control theory
- Organic chem
- Imaging
- Thermodynamics
- Modeling
- Tissue engineering
- Fluid mechanics

Percentage of programs requiring course
What is the core based on the 75% criterion?

2004 core included:
- Freshman engineering
- BME Design
- Physiology
- Mechanics
- Additional Biology
- Circuits
- Instrumentation
- Computing
- Statistics
- Materials

2019, same, but add:
- Transport (73% in 2004)
- Signal Analysis (64% in 2004)

Close to core (>50%): organic chemistry, thermodynamics, fluids
How much time is devoted to each topic in programs that require them? (2004 data; mean and SD)
II. Investigating key content

Utilized an online survey to ask about importance of 274 concepts:
• Eleven bioengineering domains (including design)
• Physiology, cellular biology, molecular biology and genetics, biochemistry
• Mathematical modeling, statistics, general engineering skills (e.g., computer programming); but not chem, physics, math

Survey to 77 faculty; 48 industry representatives (16 companies)

Participants were asked to:
• Provide demographic information
  Employer, Job Title, Responsibilities, Years of Experience
• Self-assess level of expertise in each domain (e.g., Biomechanics)
• Rate the importance/relevance of each concept to a BME core curriculum
• Suggest concepts that had not been included
Key content survey

Concepts rated on 5 point Likert Scale
1- very unimportant for all BMEs
5 - very important for all BMEs

Survey design
“Ringers” to check that unimportant concepts were rated low
Some concepts in more than one domain to check for consistency

Mean ratings across concepts similar for industry and academia
Academia (n=77) mean and SD rating: 3.71 ± 0.52
Industry (n=48) mean and SD rating: 3.75 ± 0.41

Full dataset is available, along with a couple of short ASEE papers:
• https://www.mccormick.northwestern.edu/research/engineering-education-research-center/vanth-materials/
• Or Google “Northwestern Center for Engineering Education Research” and scroll down to “VaNTH materials.”
### Results: Highest rated eng’g concepts – *Academia*

Red concepts are from statistics and general engineering domains

<table>
<thead>
<tr>
<th>Concept</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis Testing (e.g., paired and un-paired t-tests; chi-square test)</td>
<td>4.69</td>
</tr>
<tr>
<td>Principles of Statics (e.g., forces; moments; couples; torques; free-body diagrams)</td>
<td>4.68</td>
</tr>
<tr>
<td>Descriptive Statistics (e.g., mean, median, variance, std deviation)</td>
<td>4.63</td>
</tr>
<tr>
<td>Circuit Elements (e.g., resistors, capacitors, sources, diodes, transistors, integrated circuits)</td>
<td>4.56</td>
</tr>
<tr>
<td>DC and AC circuit analyses (e.g., Ohm's and Kirchoff's laws)</td>
<td>4.56</td>
</tr>
<tr>
<td>Mathematical Descriptions of Physical Systems (e.g., functional relationships, logarithmic, exponential, power-law; ODEs; PDEs)</td>
<td>4.54</td>
</tr>
<tr>
<td>Strength of Materials (e.g., stress, strain; models of material behavior)</td>
<td>4.53</td>
</tr>
<tr>
<td>Pressure-Flow Relations in Tubes and Networks (e.g., flow rate = [change in pressure]/resistance; Poiseuille relation; Starling resistor)</td>
<td>4.51</td>
</tr>
<tr>
<td>Measurement concepts (e.g. accuracy, precision, …)</td>
<td>4.50</td>
</tr>
<tr>
<td>Regression analysis</td>
<td>4.49</td>
</tr>
<tr>
<td>Forces and pressures in fluids  (e.g. shear, normal, surface tension…)</td>
<td>4.49</td>
</tr>
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Results: Highest rated eng’g concepts – *Industry*
Red concepts are from statistics and general engineering

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<tr>
<td>Descriptive Statistics (e.g., mean, median, variance, standard deviation)</td>
<td>4.76</td>
</tr>
<tr>
<td>Measurement Concepts (e.g., accuracy, precision, sensitivity; error analysis - sources, propagation of error)</td>
<td>4.71</td>
</tr>
<tr>
<td>Hypothesis Testing (e.g., paired and unpaired t-tests; chi-squared)</td>
<td>4.65</td>
</tr>
<tr>
<td>Probability Distributions (e.g., normal, Poisson, binomial)</td>
<td>4.62</td>
</tr>
<tr>
<td>Strength of Materials (e.g., stress, strain; models of material behavior)</td>
<td>4.57</td>
</tr>
<tr>
<td>Fundamental Properties of Polymers, Metals and Ceramics</td>
<td>4.50</td>
</tr>
<tr>
<td>Product Specification (e.g., requirements, design, reliability, evolution/tracking of the product)</td>
<td>4.45</td>
</tr>
<tr>
<td>Principles of Statics (e.g., forces; moments; couples; torques; free-body diagrams)</td>
<td>4.43</td>
</tr>
<tr>
<td>Mechanical Properties of Biological Tissues (e.g., elastic; viscoelastic, hysteresis, creep, stress relaxation)</td>
<td>4.43</td>
</tr>
<tr>
<td>Data Acquisition (e.g., sampling rates and analog-digital conversion; Nyquist criterion; aliasing)</td>
<td>4.39</td>
</tr>
</tbody>
</table>
Industry - Academia agreement

- Many concepts rated highly.
- All traditional domains had some highly rated concepts.

\[ R^2 = 0.65 \]
Results: Industry – Academia Agreement
Differences in mean Likert scale ratings (I-A)

Design

Bioinformatics

Enzyme kinetics; free energy

Nernst potential
Results: Discrepancies in design concepts

- Decision Matrix Approaches to Initial Design
- Design for Manufacturing and Assembly
- Software for Design and Project Management (e.g., flowcharting; Gannt and PERT charts)
- Software and Process Design Considerations
- Risk Analysis/Hazard Analysis
- Computer-Aided Design Considerations
- Human Factors Issues/FDA

Mean Ranking (all participants)

Industry
Academia

Discrepancies in design concepts
With all that material, does anything else fit?

Yes.

Also from the survey, what do people think about tracks?

<table>
<thead>
<tr>
<th>Option</th>
<th>Participants choosing option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students should follow a BME track emphasizing depth in a traditional engineering field</td>
<td>23 (29%)</td>
</tr>
<tr>
<td>Students should follow a BME track emphasizing depth in a traditional engineering field or in an emerging area (e.g., cellular engineering, systems biology, tissue engineering).</td>
<td>26 (33%)</td>
</tr>
<tr>
<td>Students should take advanced bioengineering, guided by recommended sequences, but not formalized as tracks.</td>
<td>17 (22%)</td>
</tr>
<tr>
<td>Students should be free to choose advanced courses from bioengineering, other branches of engineering, and biology.</td>
<td>12 (15%)</td>
</tr>
</tbody>
</table>
What should we do next?

- Mine data from the survey from this conference
- More conversations: e.g. What type of computer programming?
  Would more integration across courses be useful? (yes and no…)
  At what depth do concepts need to be learned?

- Communicate with industry

- Map concepts to courses locally

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<table>
<thead>
<tr>
<th>Concept</th>
<th>Course</th>
<th>EA3</th>
<th>ECE 202</th>
<th>BME 308</th>
<th>BME 320</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal Characteristics</td>
<td></td>
<td>L</td>
<td>M</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Data Acquisition</td>
<td></td>
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</tr>
<tr>
<td>Filters</td>
<td></td>
<td>L</td>
<td>L</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>System Properties</td>
<td></td>
<td>M</td>
<td></td>
<td></td>
<td>M</td>
</tr>
<tr>
<td>Fourier Analysis</td>
<td></td>
<td>M</td>
<td></td>
<td></td>
<td>H</td>
</tr>
<tr>
<td>Linear Systems</td>
<td></td>
<td>L</td>
<td></td>
<td></td>
<td>H</td>
</tr>
</tbody>
</table>
Some conclusions

From the course analysis:

- There is a core curriculum for undergrads in BME
- The core has not changed substantially for at least 15 years
- The engineering in the BME core is different than in any other engineering major – broader; and with physiology, BME is very distinct
- There is room beyond the core for students to have electives or tracks.

From the concept analysis:

- There are important concepts from a variety of domains, validating the diversity of core courses
- Industry most highly values data analysis and statistics skills
- Agreement between industry and academia suggests that academia’s sense of important concepts for industry is pretty good.
- Industry may be more interested in some practical issues than academia.
- Industry appreciates a wide variety of biological knowledge
Thanks!

A few additional slides follow
Results: Physiology (82 concepts)

- Very large span within domain
- Generally good agreement
- Cardiovascular, neural, cellular physiology concepts rated highly
- Digestive, renal, parts of endocrine rated lower
Results from concept survey: Should the following foundational courses be required?

Comparison of Responses - Industry and Academia

- Calculus - Differential, Integral and Multivariate
- Vector Calculus
- Linear Algebra
- Ordinary Differential Equations
- Physics - Waves and Optics
- Physics - Electricity and Magnetism
- Physics - Mechanics
- Chemistry - Organic (Semester Two)
- Chemistry - Organic (Semester One)
- Chemistry - General

Industry
Academia
"NO" "YES" "UNSURE"

Agreement that second semester organic chemistry is not universally required; some uncertainty about one semester
Universities represented in concept survey

1. Arizona State University*
2. Binghamton University
3. Boston University*
4. Columbia University
5. Devry Institute of Tech
6. Duke University*
7. Florida International University
8. IIT
9. Johns Hopkins University*
10. Marquette University*
11. Milwaukee SOE*
12. MIT
13. NJIT
14. NC State University*
15. Northwestern University*
16. RPI*
17. RHIT
18. Stanford University
19. Syracuse University*
20. SUNY – Stony Brook
21. Tulane University*
22. University of Akron*
23. University of Cincinnati
24. University of Illinois – UC*
25. University of Iowa*
26. University of Memphis
27. University of Michigan
28. University of Minnesota*
29. University of Pittsburgh*
30. University of Rochester*
31. University of Texas – Austin*
32. University of Toledo*
33. Vanderbilt University*
34. VCU*

*ABET Accredited – 21 of 37 Accredited Programs Participated
Companies and industrial expertise represented in concept survey

- Companies Represented
  - Abbott Laboratories
  - AstraZeneca
  - Baxter Healthcare
  - Boston Scientific
  - Cardiodynamics
  - Cleveland Medical Devices
  - Datasciences, International
  - Dentigenix, Inc.
  - Depuy, a Johnson and Johnson Co.
  - ESTECH Least Invasive Cardiac Surgery
  - GE Healthcare
  - Intel, Corp.
  - Materialise, Inc.
  - Medtronic, Inc.
  - Tyco Healthcare
  - Underwriter Laboratories

- Areas of Expertise
  - Biomaterials
  - Biomechanics
  - Bioinformatics
  - Bioinstrumentation
  - BioMEMS
  - Biotransport
  - Cellular Biomechanics
  - Computational Modeling
  - Control Systems Engineering
  - Fluid Mechanics
  - Medical Devices
  - Medical Imaging
  - Medical Optics
  - Signal Processing