AC 2009-226: BIOMEDICAL ENGINEERING CURRICULA: PRODUCING THE ENGINEERS OF 2020

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Introduction

Many engineering programs are struggling to keep their curriculum current and meet the changing needs of today's technically based society. Every engineering program needs to produce technically savvy engineers prepared for the workforce (or graduate school) while teaching them professional skills such as teamwork, leadership, and communication. Because Biomedical Engineering (BME) programs must include the ability "to solve the problems at the interface of engineering and biology" and "the ability to make measurements on and interpret data from living systems" [1] BME programs often have more difficulties including the requisite engineering topics necessary to meet ABET criteria. A good biomedical engineer must have at least a basic understanding of mechanical, electrical, and computer engineering fields as well as a strong understanding how the life sciences such as biology, chemistry, and physiology are applied at the interface of engineering and biology. This is a tall order to accomplish in a four year curriculum.

In 2004, the National Academy of Engineering published the Engineer of 2020 [2] report which contained additional recommendations on improving engineering curricula. Incorporating these recommendations as well as the skills and knowledge the ABET requires is a difficult task. This paper will detail the latest curriculum revision which implements many of the recommendations of the Engineer of 2020 report while still meeting ABET Program Outcomes.

In 2005, the faculty at the Milwaukee School of Engineering (MSOE) began a thorough review of its BME curriculum. The curriculum had been relatively stable for about 12 years with small changes made to keep the curriculum current with changes in technology. To meet the need for continuous improvement, the faculty undertook a redesign of the entire curriculum in an effort to incorporate new educational techniques and modern engineering concepts. Because of the time it takes to complete a complete curricular change, as well as the time between these large changes, the faculty spent considerable time ensuring the curriculum effectively and efficiently met current and perceived future needs of the program and its constituents. Most of the current and perceived future needs were determined from the Engineer of 2020 Report (2) as well as alumni and employer data.

Recommendations from the Engineer of 2020 Report

Several recommendations on engineering curriculum as well as skills engineers need to gain during their undergraduate career were given in the report from the National Academy of Engineering. Below are some of these recommendations [2]

1. Students and professors should be the primary actors in the learning process.
2. Engineering curricula must be better aligned with the challenges and opportunities graduates will face in the workplace
3. The teaching, learning, and assessment processes should move a student from one state of knowledge and professional preparation to another state. This should include continual improvement processes.
4. Curricula must include the application of engineering processes to define and solve problems using scientific, technical, and professional knowledge bases. These should be iterative processes and students should be taught this problem solving from the earliest stages of the curriculum.
5. Contemporary engineering devices increasingly require engineers to understand a systems perspective.
6. Students should be engaged in team-based problem solving skills in different disciplines.
7. Engineering educators should introduce interdisciplinary learning in the undergraduate curriculum.
8. Engineering students must learn how the external environment shapes the demand for engineers (e.g. business cycles and technological processes)
9. Engineering students must learn to interact with the customer and engineering managers to set goals.

Industry Input

Curricular change for the sake of change is not useful. Instead, changes to the curriculum were based on the needs of the industries and graduate school that routinely employ MSOE graduates. To support this, the Engineer of 2020 report stated that "Engineering curricula must be better aligned with the challenges and opportunities graduates will face in the workplace." (2)

To determine what challenges and opportunities that graduates actually face in the workplace, the Biomedical Engineering program elicited information from employers and graduate schools that often admit or hire MSOE BE graduates. Data was also gathered from the industry sessions of the 3rd Biomedical Engineering Summit Meeting held in 2008. From this data, the following list of skills were deemed necessary to include in the curriculum

- A strong technical background based on fundamental engineering principles
- A basic knowledge of all biomedical engineering sub-disciplines (bioinstrumentation, biomechanics including fluid mechanics, physiological modeling, imaging, biomaterials, and biosignal processing) and how they are inter-related
- Application of general engineering principles to the human body (including knowledge and application to areas in biology, anatomy, and physiology)
- Ability to find, analyze and solve a problem.
- Understanding of the design process and how it fits into the overall business processes
- A basic understanding business processes and entrepreneurial ventures

- Strong Laboratory skills
- Ability to communicate (both written and verbal)
- Understanding of regulations and ethics for biomedical situations
- Leadership and teamwork skills
- Willingness to continue to learn

Faculty

With regard to the recommendation by the Engineer of 2020 report regarding faculty and students being the primary actors in the learning process(2), it has always been an underlying belief of the administration at the Milwaukee School of Engineering that education should be provided by solely by the faculty. The institution uses only credentialed faculty who teach in the areas of their expertise and no teaching assistants. The institution also requires faculty remain current in their field and encourage professional development and consulting though various programs. This ensures that students receive the most up to date engineering knowledge and faculty can draw from their industry experiences to develop real-world content.

Curricular Inclusions

In order to meet the of the industry requirements of a strong engineering background and a basic knowledge of all subdivisions of Biomedical Engineering, the required courses in the curriculum were developed to build on and basic engineering knowledge and give students courses in each of the subdivisions. Figure 1 shows the tracks within the curriculum that illustrate this building of knowledge. Please note that prerequisite courses such as mathematics and physics are not shown. Also not shown are the physiology courses that are a pre-requisite to each biomedical course.

It can be seen in Figure 1 that the Biomedical Engineering knowledge builds on other engineering disciples such as Computer, Electrical, and Mechanical Engineering. After several courses in each of these disciplines, biomedical specific courses are taken. Please note that each box in Figure 1 represents the pre-requisite knowledge needed. Because the school runs on a quarter, and not a semester, system a greater variety of courses can be incorporated into the curriculum.

The faculty believed that this structure met the requirements of industry while helping to meet recommendation 3 of the Engineer of 2020 report (The teaching, learning, and assessment processes should move a student from one state of knowledge and professional preparation to another state. This should include continual improvement processes.) (2). This curriculum structure currently includes both assessment and continual improvement processes thereby meeting the continual improvement process recommended in the 2020 report.

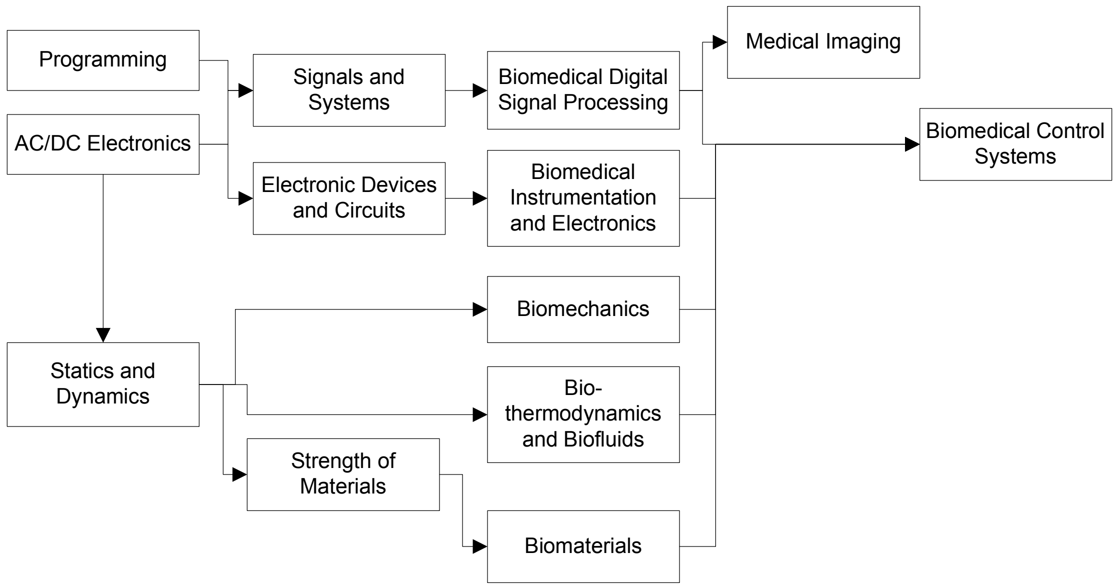

Figure 1: Diagram showing pre-requisite engineering knowledge needed for all biomedical engineering sub-disciplines included in the new curriculum. Note that courses in computer, electrical and mechanical engineering all form a foundation for future biomedical courses. This diagram does not show math, science and physiology pre-requisite knowledge that also exists in the curriculum.

<u>Other Innovations</u>

Several other innovations were placed throughout the curriculum to meet recommendations of the Engineer of 2020 report (2).

Problem Solving Throughout the Curriculum

Another recommendation from the Engineer of 2020 report (2) included was implementing engineering problem solving using previous knowledge bases throughout the entire curriculum. In order to allow their students the ability to learn problem solving techniques earlier in their academic careers, many programs have implemented freshman engineering courses. The Biomedical Engineering program has adopted this methodology and expanded it to bridge across all four years of the curriculum.

In the freshman year, students take an Introduction to Biomedical Engineering Design course in which problem solving techniques are used to design and build a rehabilitation product for a customer. This introduction to problem solving is then built upon during the sophomore year in a Matlab Programming course. Students practice the skills they learned freshman year during laboratories in which they define a problem and then solve it using a Matlab ® program. These problem solving skills are then used in all the Biomedical Engineering courses during junior and senior year.

To help students learn how to define and solve a problem, faculty have also implemented teaching techniques such as active learning and problem based learning into their courses. This forces students to hone their problem solving skills through the course and over several courses. As a result of these active/problem based courses, the students are more prepared for larger, less well defined problem based course such as senior design.

In addition to courses that use problem based techniques, the faculty believes that problem solving should be honed during laboratory periods. The curriculum was designed with thirteen biomedical engineering courses that also have associated laboratories. This is thirteen opportunities for students to learn how to define and solve a problem within the constraints of the laboratory. Faculty have structured these laboratories to be much more problem based as opposed to well defined proofs of engineering theory. This also gives the faculty an opportunity to bring in real-world problems with realistic constraints. This not only helps the program meet an ABET objective, but it also allows our students to partially meet another 2020 recommendation: "Engineering students must learn how the external environment shapes the demand for engineers" (2). By giving the students different types of realistic constraints, they learn what type of outside influence affects their designs.

Systems Perspective

The Engineer of 2020 report also recommends students should have a "systems perspective." (2) To the faculty of the Biomedical Engineering Program at MSOE, this means that students understand and can define and model the entire system, from input to output. The program has defined six sub-divisions of Biomedical Engineering, and through its curriculum wanted to ensure that the students understood each sub-division individually as well as how they all fit together. To this end, the curriculum contains an introductory signals and systems course that teaches the basics of systems and their models (input, transformation, output). After this course, students take all their individual courses in the BME subdivision as well as three joint laboratories that will be discussed later. These content areas are then brought together so that students see a "systems perspective" in three different senior year courses. The first is in the senior design sequence where students have to gather and synthesize data across disciplines to solve a real-world problem. They create block diagrams and models of their system before they break it down and design the individual components.

Of additional use to reinforce systems concepts, students take two controls courses in their senior year. These course bring together systems from each of the sub-disciplines to look at feedback control and stability in both continuous and discrete systems. By using cross-disciplinary systems for modeling and analysis student gain practice in solving problems using the "systems perspective."

Team Based Interdisciplinary Learning

Both team based and interdisciplinary learning were also recommendations of the Engineer of 2020 report (2). When designing the curriculum, the Biomedical Engineering faculty saw many places to incorporate these together.

During the freshman design course, teams are used to design, build and test a product intended for rehabilitation. Student teams work with the machine shop and the rapid prototyping center to complete these projects. In this course, the teamwork is stressed and effective team communication is discussed.

Students take this experience and apply it to their senior design courses. Students spend over two years in a team completing the senior design sequence. This includes a marketing analysis, business plan, feasibility study, system and component design, design reviews, building and testing. Students have the ability to "hire" engineers from other majors to help them complete their projects. These interdisciplinary teams help students learn what contribution other engineering majors can make to multi-disciplinary projects.

The most innovative addition to the curriculum includes three cross-disciplinary laboratories where students have to bring knowledge from (at least) two courses and solve problems at the interface of those two disciplines.

The first laboratory is a Physiology/Biosystems Laboratory where students get to take the concepts they learned about systems and apply them to physiologically relevant systems. This course contains modeling and analysis of biological systems.

The second laboratory is a Physiology/Bioflids Laboratory. In this laboratory, students apply thermodynamic and fluid concepts to physiological systems. This course also contains some statistical analysis, which brings another discipline into the system.

The final laboratory is the Biomechanics/Biomaterials Laboratory. This is the most interdisciplinary of the laboratories as students have to bring together concepts learned in physics, chemistry, statics, dynamics, strength of materials, statistics and biological systems to design and test implants and other devices.

These three laboratories help students learn that interdisciplinary not only means dealing with other engineering majors but it also requires combinations of concepts from different disciplines and prediction of responses of a complex system. These laboratories also aid students in honing their ability to think on a system level.

External Factors Influencing Engineering

Not only do tomorrow's engineers need to be prepared to design using realistic constraints, but they also have to be aware of how engineering "fits" into a company. This may include both start-ups as well as established companies. Engineers need to have a fundamental understanding of entrepreneurship, intrapreneurship, what interactions engineering has with other departments in a company and how other portions of the company (marketing, accounting, manufacturing, supply chain, etc) affects engineering decisions.

To aid students in understanding some of these factors, two business courses were added to the sophomore year. The first course discusses the basics of entrepreneurship and intrapreneurship. The second course teaches students how to write a business plan and pushes them to consider how to pitch a project to an investor. This allows the students to learn to use business terms to sell their ideas and projects to their bosses and others within the company.

The program then takes these skills they learn in the business courses and expands upon them in the design sequence. Students are required to complete a marketing study as well as a business plan and feasibility study for their senior design project before they are given the "go ahead" by "management" to move to the design phase of their project. Students are also required to maintain a complete design history record that meets all FDA requirements.

Students are also required to take one professional elective to complete their coursework. This professional elective comes from a list of approved courses that helps students hone professional skills. Some of these options include Business Communications, Advanced Technical Writing, Business Law, and Accounting. This course is one more chance for the students to learn skills outside of engineering that will aid them in communicating with other non-engineers.

Conclusion

As with the any new curriculum development, assurances that future needs of the engineering discipline are met are essential. By incorporating recommendations from the Engineer of 2020 report (2), from alumni and employer survey results, and recommendations from the 3rd Biomedical Engineering Summit, the MSOE Biomedical Engineering faculty have developed a curriculum that incorporates innovations to better prepare engineers for the future. The program faculty realize that many innovations are being done in part at other universities, but they also believe that it is accomplished more thoroughly through a hierarchical curriculum that incorporates all of these recommendations. As a result, students will build and refine the skills necessary to be a competent engineers well into the future. The complete curriculum can be seen in the Appendix.

References

1. ABET Criteria for Accrediting Engineering Programs (Effective for 2008-9, approved Nov 2007)
2. National Academy of Engineering, "The Engineer of 2020: Visions of Engineering in the New Century," *The National Academies Press*, 2004.

Appendix:

Bachelor of Science Biomedical Engineering
Model Full-Time Track - V4.1

FRESHMAN YEAR

		1	2	3
BI-102	Cell Biology and Genetics	3-3-4		
CH-200	Chemistry I	3-2-4		
EN-131	Composition	3-0-3		
HU-100	Contemporary Issues in the Humanities	3-0-3		
MA-136	Calculus for Engineers I	4-0-4		
OR-100	Freshman Orientation[1]	1-0-0		
BE-1000	Introduction to Biomedical Engineering		1-3-2	
CH-201	Chemistry II		3-2-4	
EN-132	Technical Composition		3-0-3	
MA-137	Calculus for Engineers II		4-0-4	
PH-2010	Physics I - Mechanics		3-3-4	
CH-222	Organic Chemistry I			2-2-3
EN-241	Speech			2-2-3
MA-231	Calculus for Engineers III			4-0-4
MA-3610	Biostatistics			4-0-4
PH-2020	Physics II - Electromagnetism and Optics			3-3-4
	TOTALS	**17-5-18**	**14-8-17**	**15-7-18**

SOPHOMORE YEAR

		4	5	6
BE-2200	Computing in Biomedical Engineering	3-3-4		
CH-223	Biochemistry	3-2-4		
MA-235	Differential Equations for Engineers	4-0-4		
ME-205	Engineering Statics	4-0-4		
MS-3425	Entrepreneurship - An Overview	1-0-1		
EE-201	Linear Networks: Steady-State Analysis		4-0-4	
ME-206	Engineering Dynamics		4-0-4	
MS-3427	Entrepreneurial Business Plans		1-0-1	
PH-2030	Physics III - Thermodynamics and Quantum Physics		3-3-4	
SS-461	Organizational Psychology		3-0-3	
BE-2000	Biomedical Engineering Design I			1-0-1
BE-206	Signals and Systems I			3-3-4
EE-2920	Embedded Systems			3-3-4
MA-232	Calculus for Engineers IV			3-0-3
ME-207	Mechanics of Materials			3-2-4
	TOTALS	**15-5-17**	**15-3-16**	**13-8-16**

JUNIOR YEAR

		7	8	9
BE-3000	Biomedical Engineering Design II	1-2-2		
BE-3100	Quantitative Systems Physiology I	3-0-3		
BE-3500	Bio-Thermofluids	4-0-4		
BE-3800	Biomedical Systems II	3-0-3		
BE-3900	Physiology and Bio-System Joint Laboratory	1-2-2		
	Elective[2]	3-0-3		
BE-3001	Biomedical Engineering Design III		1-2-2	
BE-3110	Quantitative Systems Physiology II		3-0-3	
EE-3111	Electronic Devices and Circuits		3-3-4	
BE-3510	Biotransport		3-0-3	
BE-3910	Physiology and Biotransport Joint Laboratory		1-2-2	
	Elective[2]		3-0-3	
BE-3002	Biomedical Engineering Design IV			1-2-2
BE-306	Biomedical Instrumentation			3-3-4
BE-3920	Biomaterials and Biomechanics Joint Laboratory			1-2-2
BE-410	Biomaterials			3-0-3
BE-411	Biomechanics			3-0-3
HU-332	Bioethics			3-0-3
	TOTALS	**15-4-17**	**14-7-17**	**14-7-17**

SENIOR YEAR

		10	11	12
BE-4000	Biomedical Engineering Design V	2-3-3		
BE-417	Biomedical Electronics	3-3-4		
BE-4800	Biomedical Digital Signal Processing	2-3-3		
	Elective[2]	3-0-3		
	Elective[2]	3-0-3		
BE-4001	Biomedical Engineering Design VI		2-3-3	
BE-4810	Biomedical Feedback Systems I		3-3-4	
BE-4830	Medical Imaging Systems		3-0-3	
	Elective[2]		3-0-3	
	Elective[2]		3-0-3	
BE-4002	Biomedical Engineering Design VII			2-3-3
BE-472	Biomedical Control Systems: Digital			3-3-4
	Elective[2]			3-0-3
	Elective[2]			3-0-3
	TOTALS	**13-9-16**	**14-6-16**	**11-6-13**

[1] Transfer students who have completed 36 quarter or 24 semester credits will be waived from OR-100, but will be required to complete OR-301 Transfer Orientation.

[2] There are 24 credits (8 courses) of electives that must be taken as detailed:

- 15 credits (5 courses) must be humanities and social science (HU/SS) electives, of which 6 credits must be taken in the humanities area, 6 credits in the social science area, and 3 credits in either area.
- 6 credits (2 courses) must be technical electives taken from the approved list.
- 3 credits (1 course) must be a professional elective taken from the approved list.

Students in the Air Force ROTC may take the following substitutions: AF-401 for 1 technical elective and AF-402 for 1 professional elective. All other AF courses must be scheduled in addition to the courses listed above.

Accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET, 111 Market Place, Suite 1050, Baltimore, MD 21202-4012; telephone: (410) 347-7700).