

Biomedical Engineering for All Electrical Engineers: A Model for Integrating Novel Content into Existing Curriculum

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Abstract: Biomedical engineering (BME) is one of the fastest growing industries, with an expected job growth rate that is twice that of the overall job growth rate in the US. However, ABET lists only 28 schools offering accredited undergraduate degrees in BME, and particularly under current economic conditions, most schools do not have the resources to offer new degree programs. The resulting gap between the demand for qualified BME professionals and the programs for educating them constitutes a significant, yet unmet, national need. Our goal is to develop a new educational paradigm to help reduce this gap.

This paradigm is based on introducing novel multidisciplinary content into core engineering curriculum, and it consists of integration of content specific laboratory experiments into core courses to provide essential background, followed by an elective providing topical depth. BME is used as the novel content and ECE as the core curriculum. The method is versatile, as it can be easily modified to integrate other novel multidisciplinary content into any engineering program. We have two specific objectives: (1) to provide ECE students with fundamental and contemporary BME knowledge for future career and graduate study opportunities; and (2) to improve students' interest in and comprehension of ECE concepts by acquainting them with engineering solutions to real world problems in medicine. These objectives are achieved by integrating a set of experiments – designed to demonstrate a wide spectrum of BME concepts – into core ECE courses, along with a new elective providing a comprehensive BME overview.

Expected outcome of this project is a learning paradigm, serving as a model for integrating novel content into core engineering curriculum. If proven successful, the full development of this approach can serve as a building block for future undergraduate minor / concentration programs in a variety of novel content areas, such as biomedical engineering. In this paper, we present the paradigm, its implementation, and some preliminary results on early, yet limited implementation.

1. Introduction

Biomedical engineering (or bioengineering – BME) is emerging as one of the fastest growing fields in the US, not only due to its significant impact in the healthcare industry, but also due to its influence on other engineering and technology industries. U.S. Dept. of Labor estimates that the job market for biomedical engineers will increase by 31.4%, faster than the average of all occupations, through 2010. This is double the overall job growth rate of 15.2% and more than three times the overall growth rate of 9.4% for all engineering jobs^{1,2}. However, BME education has not kept pace with this rapid growth and development. There are fewer than 90 institutions in the US offering some form of a BME program, mostly at the graduate level³. In fact, only 28 of these institutions offer an accredited undergraduate BME degree program⁴.

As we look at the number of degrees conferred, the situation is not looking too bright for BME, despite its recently growing numbers. Prism's January 2004 issue reports that in 2002 67,301 bachelor's engineering degrees were conferred in the US, of which 21,813 were in Electrical / Computer Engineering (ECE), 8,799 in Civil, 5,570 in Chemical, and a mere 1,254 were in BME⁵. The result is a clearly increasing gap between the demand for qualified BME professionals, and available programs for educating them, causing a significant, yet unmet, national need.

The obvious solution to address this need is to create new undergraduate BME degree programs. However, creating a new program requires significant resources and a substantial investment, which is difficult to attain even during the best of economic conditions. From a financial viewpoint, a new degree program is simply beyond reach for most institutions. The above-mentioned gap cannot be closed simply by increasing the capacity of the existing programs either, due to the incremental and geographically restricted nature of this approach.

An alternate approach that integrates multidisciplinary novel content into an existing core curriculum may provide students with essential knowledge on the novel content, while requiring little or no additional resources. This proposal describes such an approach for establishing this proof of concept by using multidisciplinary BME topics as the novel content and the electrical and/or computer engineering (ECE) curriculum as the existing core discipline.

At the heart of this prototype lies a set of experiments, designed to demonstrate fundamental BME concepts and relevant topics of underlying physiology, integrated into select ECE core courses, along with a new senior elective course providing a comprehensive BME overview. The prototype uses ECE as the base curriculum primarily due to the expertise of the investigators in this field. However, the approach described in this proposal can easily be modified for other engineering programs, on any novel content, by suitable choice of experiments.

From a BME education perspective, the approach is certainly not a substitute for a full-fledged degree program, however, we believe that it has significant potential in reducing the shortfall for qualified BME professionals, since it can be easily implemented by any one of over 290 electrical, 264 mechanical, 162 chemical or other interested engineering programs.

Our project whose primary goal is to achieve the above mentioned paradigm for integration of BME concepts in the ECE curriculum has recently been funded by the Course Curriculum and Laboratory Improvement program of the National Science Foundation. In this paper we describe the paradigm in detail along with its strengths, its implementation and present some very preliminary outcomes – as an early update – on its limited implementation to date.

2. Goals and Objectives

Our main goal is to develop a prototype that provides a better-rounded engineering education in general, and that imparts fundamental and contemporary BME knowledge, in particular. Towards this goal, we are developing a prototype that can potentially be used as a national model primarily by engineering colleges and departments that would like to provide a multidisciplinary BME content for their students, but lack the necessary resources to provide a full-fledged degree program. Closely related to this goal, our work has two specific objectives:

1. Impart fundamental and contemporary BME knowledge for *all* our ECE students who will join the engineering workforce, and provide fundamental BME background for those who wish to pursue career or graduate education opportunities in BME related fields. This objective will be achieved by exposing students to a wide selection of BME topics through carefully designed experiments demonstrating both ECE and BME concepts. For students who express inter-

est in BME, the concepts learned through the experiments will be complemented by a senior level elective providing a broader BME background. The experiments will be distributed throughout the ECE curriculum, providing a 4-year, continuous exposure of BME topics, which are inherently multidisciplinary.

2. Improve students' learning and comprehension of ECE concepts by motivating them through continuous exposure to multidisciplinary real world problems in medicine. Such exposure to multidisciplinary concepts, particularly when accompanied by appropriate laboratory experience, has been shown to help students better adapt to industry, make better connection between theory and practical design, and enhance creativity, analytical thinking, and communication skills^{6~10}. In this project, this goal is achieved by strategically designing experiments that demonstrate solutions to multidisciplinary problems that students can associate with their own daily experiences. We further believe that achieving this objective will also allow us to increase recruitment and retention of engineering students. This is because, introducing science, engineering, mathematics and technology principles through hands-on applications of familiar systems is more likely to enthuse and motivate students to study and complete an engineering degree; as it has been shown to be extremely effective in attracting and retaining engineering students^{11~16}. The human body provides "a theme" as an excellent example for such a familiar system.

Our long-term vision for the full development of this project is the complete integration of a full spectrum of BME topics into the entire ECE curriculum, with additional elective courses designed to provide a minor or concentration in BME. If successful, this approach can then be used for integrating BME into other engineering disciplines within a college of engineering, which may then serve as the foundation of an interdepartmental undergraduate BME degree program.

3. Implementation

Teaching new BME concepts primarily in a laboratory setting fits naturally to Rowan's ECE program¹⁷, the key attributes of which include the following techniques to prepare students for a rapidly changing and highly competitive career market. (1) Multidisciplinary and hands-on education where each course is complemented with laboratory experience; (2) an emphasis on teamwork as the necessary framework for solving increasingly complicated and open ended

problems; (3) incorporation of state-of-the-art technologies throughout the curriculum; and (4) creating opportunities for improving technical communication and analytical thinking skills. The experiments developed within this project are all designed to feature these four key attributes, all of which constitute an integral part of ABET's criteria for evaluating engineering programs¹⁸.

The proposed prototype includes eight experiments to be incorporated into the ECE core curriculum, along with a new technical elective with its own semester long project to achieve the above stated goals and objectives. Depending on the specific class, the experiments can take anywhere from 3 to 15 weeks in courses whose laboratory module meet once a week. The experiments are designed to be increasingly complex and open-ended particularly after the junior level.

We emphasize that a very important aspect of our project is to provide a broad background in biomedical engineering, not just picking applications of electrical engineering in medicine. This requires a reasonable amount of anatomy and physiology knowledge. A portion of the time available for each experiment is therefore used in "Anatomy & Physiology (A&P) Modules" to discuss the underlying anatomy and physiology concepts relevant to the experiment. These modules are taught by a faculty member from the Department of Biological Sciences.

The experiments proposed for the proof-of-concept are described below, along with the class for which they are designed, and the targeted ECE and BME concepts to be learned. Unless noted otherwise, students will acquire their own biological signals using medical grade isolated biopotential amplifiers, to increase their motivation and interest.

3.1 A. Experiments Designed for Select Core Courses

1. Measurement of Biological Signals and Indicators (Freshman Clinic I): This class, common to all engineering students, introduces basic measurement concepts and proper procedures for reporting these measurements¹⁹. In this experiment, students will acquire, plot and interpret their own biological signals and indicators, including electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG), lung volumes, and non-invasive blood pressure. They will also perform basic statistical analysis, such as class mean, variance and histogram of heart rate, blood

pressure, forced expiratory volume, etc. This experiment will feature additional A&P modules (1½ hours each week for three weeks), where students will be introduced to very essential concepts and terminology of cardiovascular, muscular, neural and respiratory physiology. A&P modules of subsequent experiments will provide expanded coverage on these topics. Introductory statistical concepts of mean, variance and normal distribution, as well as an overview of ECE concepts of data acquisition and sampling will also be discussed.

2. Reverse Engineering of Automated Blood Pressure Monitor – (Freshman Clinic II): Also common to all engineering students, this class introduces engineering devices and mechanisms through reverse engineering²⁰. Students will reverse engineer and comparatively assess competing automated blood pressure monitors. They will learn how various components work individually as well as how they are integrated to work together. These components include pressure sensor and transducer, liquid crystal display, microprocessor, inflating pump motor, and the solenoid valve. Engineering topics to be introduced include basic circuit concepts, total cost of ownership through power consumption analysis, pressure sensors, motor efficiency, airflow measurements and engineering economics. A&P modules will concentrate on cardiovascular dynamics, particularly the cardiac cycle and pressure/volume relationships, as they relate to blood pressure.

3. Electrical Safety (Networks II): Networks I and II teach analysis of resistive, capacitive and inductive circuits. This experiment will introduce students to isolated power systems and electrical safety measures to be addressed in designing medical equipment. A software based human physiology simulator will be used to demonstrate various parameters affecting electric shock. Students will build electric safety testers and ground fault circuit interrupters using concepts from Networks I and II. A&P modules will concentrate on membrane, threshold and action potentials, sensory receptions via the skin and reflex responses to provide an understanding of skin and body resistance, threshold of perception, and physiological effects of current.

4. Biopotential Amplifiers (Electronics I): Electronics I introduces basic electronic components and amplifier design strategies. In this experiment, students will design and build a breath analyzer to estimate alcohol concentrations, which will be simulated using various concentrations of ethanol in a test tube. ECE concepts to be introduced include isolation preamplifiers, dif-

ferential amplifiers, AC/DC coupling for noise suppression, and basic filter design. A&P modules will discuss the autonomic nervous system (ANS) and ANS controlled reflexes to describe biofeedback with its applications on physiological events triggered under alcohol consumption.

5. Cardiac Monitor for Arrhythmia Detection (Digital II): Digital I and II are concerned with logic circuit design and applications of microprocessors, respectively. In these courses, the laboratory experiments are designed as semester long projects. Cardiac monitor for arrhythmia detection is a relatively complex system featuring many modules, such as data acquisition and sampling, signal conditioning, cardiac tachometer design for determining the heart rate, algorithm design for detecting a select group of arrhythmias, software design for the microprocessor, etc. Therefore, this experiment will last an entire semester, and will be used as an intermediate milestone in assessing students' interest in BME. Only a portion of students will be assigned the BME experiment, whereas the rest will continue to work on non BME related laboratory exercises. A blind survey will be conducted to assess students overall response. A&P modules for this experiment will discuss the conduction system of the heart followed by flow / pressure / volume relationships, as an essential background for understanding what cardiac arrhythmias signify and how they are characterized.

6. Signal Denoising and Compression (Digital Signal Processing): DSP introduces time and frequency domain analysis of digital signals and digital filter design criteria for signal processing. Students will design appropriate low/band/high pass and notch filters for denoising ECG signals corrupted by EMG activity and line noise. They will learn spectral characteristics of ECG and EMG signals, as well as designing appropriate digital filters. They will also be introduced to algorithms specifically designed for compressing biological signals. A&P modules will discuss additional topics in muscular physiology, including the theory of muscle contraction, muscle membrane depolarization and repolarization, muscle group actions and the basics of movement.

7. Biotelemetry (Communication Systems): This class teaches modulation techniques and communication systems. Biological signals are often transmitted using digital and wireless communication techniques. Students will work in teams to build a biotelemetry system for transmitting noisy ECG/EMG/EEG signals. The system will include the modules of data acquisi-

tion, sampling, baseband digital modulation, bandpass modulation for transmission, detection and demodulation of the signal. A&P modules will review neuronal conduction, the similarities and differences among EEG, ECG and EMG, and the integumentary system as a vehicle for conduction of electrical signals.

8. Physiological Modeling of Lung Mechanics (Control Systems): This class teaches basic system theory, modeling and strategies for closed loop control systems. In this experiment, students will develop a simple model of lung mechanics from empirical measurements of volume flow rate, air pressure and concentrations of various gases at the airway opening (using a cardiopulmonary function analyzer). Students will then investigate the biodynamic control of respiration. They will explore the effects of dead space (simulated by breathing through a tube) on tidal volume and frequency of breathing empirically, and effects of exercise on the respiratory system. A&P modules will discuss the mechanics of breathing, regulation of respiration, and further examine the concepts of negative pressure in relation to respiration, pressure gradients and gas exchange in the lungs.

3.2 Technical Elective: Principles of Biomedical Systems and Devices

A new technical elective, to be taught during the senior year, is being developed for students who consider a career or graduate work in BME. All students will already have obtained prior BME background and motivation by their senior year, and therefore this class will not be just an isolated technical elective. The course will first review previously introduced topics, with relevant A&P background, with particular emphasis on origin of biopotentials, the Hodgkin-Huxley model, electrodes and transducers for measuring biopotentials, cardiovascular and neuromuscular systems along with their associated measurements. Other measurement techniques, such as spirometry and respiratory plethysmography, blood flow and blood volume measurements will then be discussed, followed by a survey of more contemporary topics of clinical instruments for laboratory analysis and medical imaging systems.

A design oriented semester long project will serve as the laboratory component for this course. Students will be working in groups on designing modules of a complete system, requiring them to combine their knowledge on various ECE, BME and A&P topics discussed through-

out the four years of BME exposure. A different system will be featured as the design project in each offering of this course. Students will be given design specifications that would be relaxed enough to ensure that the project can be completed within a semester, yet realistic enough to demonstrate the intended concepts.

3.3 Plans for Full Development

Upon successful completion of this proof-of-concept project (Phase I) – as determined by the outcome of evaluation efforts – our full-development plans (Phase II) for this project include designing additional experiments for other core and regularly offered elective courses. These core courses include electromagnetics, computer architecture and Electronics II (VLSI design), whereas the electives include image processing, wavelets, pattern recognition, adaptive filters, neural networks, instrumentation, DSP architectures, RF electronics and optics. The experiments designed for electives will be drawn from advanced topics of BME that are closely related to faculty's research.

Our longer-term plans include developing additional BME related technical electives, such as bioinstrumentation, biomaterials and biomechanics in collaboration with other engineering departments to create a specialization area in BME. Our vision is to be able to use this model as a building block for a prospective degree program in biomedical engineering.

4. Preliminary Outcomes

So far, we have designed and implemented the experiments on reverse engineering of blood pressure monitor (for Freshman Engineering Clinic II) and the cardiac / arrhythmia monitor (for Digital II). We have also designed the experiments on biopotential amplifiers (for Electronics I) and signal denoising (for Digital Signal Processing), however these experiments have not yet been implemented by students. We have also developed the elective course, Principles of Biomedical Systems and Devices and offered it as an experimental special topics course. The course had a considerable interest from students as twenty-two students signed up for the course, who represented about 80% of our senior population. Student evaluations indicated that all students enjoyed the course, however, a more measurable outcome is the number of students who actually applied for a graduate program in biomedical engineering. Two students applied – and were admitted - to prestigious graduate programs, and one additional student applied and admitted to a

graduate program in ECE where she in fact is working on a BME related project. These numbers may seem small but they represent a significant change, as none of our graduates – since our first graduating class in 2000 - have ever applied to a BME graduate program before and/or worked on a BME related graduate research project.

We have also conducted a survey on students taking the Digital II class, a random portion of whom worked on the BME experiment. In this anonymous survey, we first asked students to indicate the project they worked on, whether – on a scale of 1 to 5 – they feel they have made the right decision by choosing engineering and/or ECE. Using these questions we were able to identify those students who participated in the BME experiment, as well as whether their answers to other questions would be corrupted due to some dislike towards engineering or ECE in general. We then asked them rate on a scale of 0 – 1 – 2 , which of the 11 ECE related areas they found interesting and/or exciting, which areas they would consider for graduate study and / or immediate career. One of the 11 fields was biomedical engineering. We also asked them to rank their interest in any of the 20 ECE related electives, of which three were BME related (PBSD – principles of biomedical systems and devices, medical electronics and medical imaging). An answer of “0” indicates no interest, “1” indicates interest and “2” indicates a strong interest. We would like to note that, in constructing this survey, we had three major intentions: (1) determine the true interest this course may have produced in BME, (2) test this interest in more than one way by asking similar questions multiple times – but in slightly different forms, and (3) hide the true intent of the survey from the students, which we hoped to achieve by hiding BME related items in a large number of other choices.

The following two tables summarize the results for the BME related sections of the survey for 6 students who participated in a BME related project (Table 1) and 11 students who did not (Table 2). The last column gives a BME overall interest indicator for each student, which is the sum of all points in columns three (interested in BME?) through eight (Career in BME?). The maximum score that can be attained is twelve, if the student expresses strong interest in all BME related activities (that is, strong interest in all classes, strong interest in a BME related graduate program, career, etc.). We note once again, that the different questions asked are in fact related, and hence not independent, and one may argue that all these questions test more or less the same

thing. This is precisely what we intended: naturally, we did not expect students who had no interest in any of the BME courses to have a strong interest in a BME related graduate program / career, or vice versa. The goal, as mentioned above, was to test the true interest level of the student, and separate those who had mixed feelings and/or a specific interest in a very narrowly focused area of BME (such students, for example, would reveal themselves by a strong interest in one specific course, but no interest in the field in general).

Table 1. Survey results of students who did participate in a BME related project

		Participated in a BME Experiment						
Satisfied with		Interested in BME ?	Courses			Graduate Study in BME ?	Career in BME?	Total Score
ENG	ECE		PBSD	Medical Electronics	Medical Imaging			
4	4	0	1	1	1	1	1	5
5	5	1	2	2	2	1	2	10
4	2	0	0	0	0	0	0	0
4	4	1	1	1	1	1	1	6
3	3	2	2	2	2	2	2	12
4	4	0	0	0	0	0	0	0
Mean								5.5
St. Dev.								4.9

Table 2. Survey results of students who did not participate in BME related project

		Did NOT Participate in a BME Experiment						
Satisfied with		Interested in BME ?	Courses			Graduate Study	Career in BME	Total Score
ENG	ECE		PBSD	Medical Electronics	Medical Imaging			
4	5	0	0	0	0	0	0	0
4	4	0	0	1	0	0	0	1
5	5	0	0	0	0	0	0	0
3	3	2	1	1	0	0	0	4
3	3	0	0	1	1	1	1	4
5	5	0	0	0	0	0	0	0
5	5	0	0	0	0	0	0	0
5	5	0	0	0	0	0	0	0
5	2	0	0	0	0	0	0	0
5	5	2	2	2	2	2	2	12
5	5	1	0	2	1	2	2	8
Mean								2.6
St. Dev.								4.1

The above tables indicate that the students who were involved in a BME related experiment were, in general, more interested in BME at the end of the semester, compared to those who did not. We would have liked to declare an absolute success simply by looking at the above table and pointing out that the overall BME interest in the former group (5.5) is more than double that of the latter group (2.6). However, we will refrain from doing so – at least for the time being – for two main reasons: First, the standard deviations are rather high and the number of students is low, invalidating any statistical claims of success (in fact, we can only claim that the two means are statistically different at a 75% confidence level using a paired t-test). Second, we have only done this on one class of students.

We would like to point out a few other observations that are worth noting. The third student in the BME experiment group indicated that he was rather unsatisfied with ECE, and since the experiment was in fact closely related to ECE, it is not surprising that s/he showed no interest in BME. This case could be considered as an outlier; however, we decided to include it in the analysis to be more conservative. Conversely, the last two students in the non-BME experiment group indicated a strong interest in BME, which could be due to a former interest in the field. We feel that the A&P modules of the course benefited these students as well and further elevated their interest.

The limited implementation of the project does not allow us to make statistically significant claims, however, we are in fact very pleased with the promising results; not only with the elevated levels of BME interest in students who participated in the BME experiments, but also in the significant jump in our seniors going to BME related graduate programs.

5. Conclusions

We are currently working on an ambitious, multi-year plan for establishing a new paradigm specifically designed to integrate novel content material into the existing curriculum. This paradigm is to develop new laboratory exercises tailored to provide content specific knowledge that relates to the focus areas of existing courses. In our implementation we use biomedical engineering (BME) as the novel content and electrical and computer engineering (ECE) as the core curriculum, with two primary objectives: to provide ECE students with fundamental and contempo-

rary BME knowledge for future career and graduate study opportunities; and to improve students' interest in and comprehension of ECE concepts by acquainting them with engineering solutions to real world problems in medicine. We have chosen BME as the novel content due to alarmingly growing gap between the need for qualified BME professionals and actual number of students graduating with such qualifications. This approach has several advantages: (1) it is versatile, any number of topics can be integrated that the faculty deems important; (2) a broad spectrum of topics can be addressed as they are distributed throughout the 4-year curriculum, (3) all students are exposed to novel content, not just a select few who take elective courses; (4) very little additional resources are required for implementation; (5) students receive a more well-rounded and broad education within their specific disciplines; (6) experiments are integrated into existing courses, keeping credit count unchanged; (7) electives can then be devoted to covering depth in specific issues, and students will be able to make better informed decisions about choosing related electives. Preliminary outcomes indicate that the approach has strong potential of success in the long run.

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