Laboratory Integration of Emerging Topics into Existing Curriculum

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Abstract – **The growing body of scientific and engineering knowledge, against the current economic and political realities restricting the number of credits required to obtain a degree, constitutes a significant challenge in designing tomorrow's engineering curriculum. More novel content from emerging areas of engineering needs to be integrated into the curriculum, without sacrificing the fundamental background, and without increasing the credit count. We propose a laboratory based approach to this dilemma, where the novel content is introduced as applications within the laboratory exercises of the course with the closest topical area within the existing curriculum. We use biomedical engineering concepts as the novel area and electrical & computer engineering courses as the existing curriculum in our implementation, to increase awareness and interest in biomedical engineering. We discuss our reasons for choosing biomedical engineering as the novel content, present the implementation details of our approach, as well as the assessment results of our initial implementation.**

Index Terms – Integration of novel content, biomedical engineering, laboratory exercises.

INTRODUCTION

The recent proliferation of scientific knowledge allows engineers to tackle increasingly complex problems. However, as the complexity increases, so does the number of different expertise areas required to solve such problems. To be competitive, engineers need not only a comprehensive background in their chosen field, but also adequate exposure to as many emerging fields as possible. Such exposure enables them to quickly acquire new knowledge and skill sets in a previously unfamiliar area. Our challenge is then to find the most efficient, economical and pedagogical way to integrate such emerging topics into their existing curriculum.

Elective courses in emerging areas have traditionally been offered to meet such a need. Such courses certainly play an important role in providing exposure to additional topics, and we too take advantage of this valuable tool. However, with only a few (usually one) electives per topical area, either depth or breath must be sacrificed, only limited amount of material can be covered, and students who may not have prior background or exposure about a given topic may feel hesitant in electing such a course. Furthermore, given the recent decline in the number of credits required to earn an engineering degree, there is often little room in the curriculum for additional electives.

Against this background, we propose another traditional tool, but this time specifically configured to integrate novel content into existing curriculum: develop laboratory exercises – distributed over several years and integrated into core courses – strategically designed to provide content specific knowledge that relate to focus areas of existing courses. In our implementation, we use bioengineering/biotechnology (BME) as the novel content area, and electrical/computer engineering (ECE) as the core curriculum. We have two objectives in doing so: to expose ECE students to this fast growing field by providing them with fundamental and contemporary BME knowledge; and to improve their comprehension of ECE concepts by relating such concepts to real world problems in medicine. In this paper, we first discuss our reasons for choosing BME as the pilot emerging topic area, followed by implementation and assessment details. We then present pleasantly surprising outcomes of our two-year efforts, and conclude with discussing advantages as well as challenges associated with the proposed approach.

BIOMEDICAL ENGINEERING AS AN EMERGING AREA

Biomedical engineering (or bioengineering – BME) is emerging as one of the fastest growing fields in the US. The increasing public concern for well-being, as well as the aging population in the US, intensify the focus on health issues, which then drives the demand for better medical devices, equipment and processes designed primarily by biomedical engineers [1]. As of November 2005, the US Department of Labor estimates that the job market for biomedical engineers will increase by 30.7%, much faster than the average of all occupations, through 2014. This is more than double the overall job growth rate of 13.0%, and the overall engineering growth rate of 13.4% [1,2]. According to 2002 figures, there were about 7,600 biomedical engineering jobs in the United States, and was expected to exceed 10,000 by 2012. Yet, the figure of 10,000 was reached by November 2005 [2]. The rapid growth in BME certainly fueled the growth in programs offering BME education: there are now 119 institutions (up from 42 in early 1990s and up from 90 in early 2000s) in the US offering some form of a BME program, mostly, however, at the graduate level [3]. In fact, only 36 of these institutions offer an accredited undergraduate BME degree program [4].

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Furthermore, the ASEE 2005 survey on engineering education reports that 72,893 B.Sc. engineering degrees were awarded in the US: 21,038 in Electrical and/or Computer Engineering (ECE), 14,182 in Mechanical 8,718 in Civil/Environmental, 4,801 in Chemical, and 2,019 in BME [5]. The result is an increasing gap between the demand for qualified BME professionals, and available programs for educating them, causing a potentially significant, yet unmet, national need.

The obvious solution to address this need is to create new undergraduate BME degree programs, and some schools do exactly that: University of California, Los Angeles, has just started accepting students to its new bioengineering program. There has been an overwhelming interest in the new program with over 2000 applicants for 35 seats [6], indicating the growing BME interest among nation's high school seniors. However, creating a new program is a major challenge that requires significant resources and a substantial investment, a proposition difficult to attain even during the best of economic times. Considering that The Whitaker Foundation, the major supporter for new BME programs – with over $720 million for 30 new bioengineering departments – is shutting down in June 2006, creating a new degree program will simply be beyond reach for most institutions. Another option is to increase the capacity of the existing programs, however, such an approach is only incremental and geographically restricted in nature.

Hence we would like to draw attention to a set of interrelated problems: First, solutions to increasingly complex engineering problems require expertise in multiple areas, and providing such wide scoped expertise within one degree program is a very challenging prospect under the given economic and curricular restrictions. Second, we have an emerging and rapidly developing field of study (biomedical engineering) for which there is significant demand. Yet, we are unable to meet this demand with the current undergraduate programs due to enormous resources a new program requires. Hence we are compelled to consider innovative solutions that can address these interrelated problems.

In this paper, we propose an alternative approach, integrating multidisciplinary novel content into an existing core curriculum for providing students with fundamental background and knowledge on the novel content area, while requiring very modest additional resources. Due to the above described rapid growth in BME, combined with the authors' background and interest, BME was our natural choice as the novel content area, and ECE as the existing core discipline.

The proposed approach itself - developing new laboratory exercises - is not an innovative technique per se: it has been used for centuries to demonstrate the practical applications of theoretical concepts. However, we would like to use this well-established approach in a new setting, namely, integrating novel content into existing curriculum. Essentially we develop a set of laboratory exercises, designed to demonstrate fundamental BME concepts, and associated relevant topics of underlying physiology, integrated into select ECE core courses. Such exercises are used to expose the students to BME and hopefully elevate their interest and appreciation in this area. We then complement such exposure with a new senior elective course providing a more comprehensive and in-depth BME overview.

We would like to note that the approach described in this paper 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. This is because the approach can be easily implemented by any one of nation's over 300 electrical, 270 mechanical, 160 chemical or other interested undergraduate engineering programs, and students who are exposed to BME through such a program can then choose one of over 100 graduate degree programs in BME or other related biotechnology disciplines.

Yet, the main benefit of the approach is that it can easily be modified for any engineering programs, on any novel content by suitable choice of laboratory exercises.

The preliminary outcomes of our approach were reported in [7]. In this paper we describe the approach in greater detail along with its strengths, its implementation, new outcomes since last year, as well as some lessons learned during our first year and a half experience.

IMPLEMENTATION DETAILS

We have two specific objectives within the scope of this work. First, we would like to expose our students to a wide selection of multidisciplinary BME topics, to enable those who may wish to pursue future school/career opportunities in BME related fields. Our second objective is mostly of pedagogical value: exposing students to multidisciplinary concepts, particularly when accompanied by appropriate hands-on laboratory experience, has been shown to improve their motivation, help them better adapt to industry, make better connection between theory and practical design, and enhance creativity, analytical thinking, and communication skills [8-12]. Therefore, we specifically select experiments that demonstrate solutions to multidisciplinary problems that students can associate with their own daily experiences. The human body provides a suitable theme for such an objective.

Towards these objectives, we propose a prototype that consists of carefully selected experiments demonstrating both ECE and BME concepts. For students who express interest in BME, the concepts learned through the experiments are then complemented through a senior level elective providing a broader BME background. The experiments are distributed throughout the ECE curriculum, providing a 4-year, continuous exposure of BME topics.

The proposed prototype includes eight experiments to be incorporated into the ECE core curriculum, along with a new technical elective with its own experiments and projects. Depending on the specific class, the experiments can last from 1 to 15 weeks. The experiments are designed to be increasingly complex and open-ended particularly after the junior level. We acknowledge that a meaningful anatomy and physiology background is also necessary to fully understand the complexity of the system for which the devices and equipments are designed. Therefore, we assign a portion of the time available for each experiment to "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.

I. Experiments for Core Courses

The following experiments constitute our proof-of-concept study. Unless noted otherwise, students acquire their own biopotentials, using medical grade isolated biopotential amplifiers, to increase their motivation and interest.

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 measurements [13]. In this experiment, students acquire, plot and interpret their own biological signals and indicators, including electrocardiogram (ECG), blood volume change, lung volumes, and non-invasive blood pressure. They also perform basic statistical analysis, such as class mean, variance, and histogram of measured parameters to compare the effects of gender, fitness, weight, and smoking habits on these parameters. In the A&P modules, students are introduced to essential concepts and terminology of cardiovascular and respiratory physiology.

2. Reverse Engineering: Automated Blood Pressure Monitor (Freshman Clinic-II): Also common to all engineering students, this class introduces engineering devices and mechanisms through reverse engineering [14]. Students reverse engineer and comparatively assess competing automated blood pressure monitors. They learn how various components work individually, and how they are integrated to work together. These components include pressure sensors and transducers, liquid crystal display, microprocessor, inflating pump motor, and the solenoid valve. Basic circuit concepts, total cost of ownership through power consumption analysis, pressure sensors, motor efficiency, airflow measurements and engineering economics are covered as engineering topics. A&P modules concentrate on cardiovascular dynamics, particularly the cardiac cycle and pressure/volume relationships, as they relate to blood pressure.

3. Bio-signal amplification and filtering (Networks II): Networks I and II teach analysis of resistive, capacitive and inductive components for the analysis of basic amplifier and filtering circuits. In this experiment students design a simple amplifier and a low pass filter to properly acquire their own ECG signals. A&P modules for this experiment 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 electrical current.

4. Biopotential Amplifiers (Electronics I): Electronics I introduces basic electronic components and amplifier design strategies. We have different experiments for this class and students can choose one they find more interesting: in one experiment, students design and build a breath analyzer to estimate alcohol concentrations, simulated by using various concentrations of ethanol in a test tube. In the alternate experiment, students will be asked to design a complete ECG amplifier along with its proper (hardware) filters. ECE concepts to be introduced include isolation preamplifiers, differential amplifiers, AC/DC coupling for noise suppression, and basic filter design. A&P modules 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 II is concerned with microprocessor based design. In this course, the 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 lasts an entire semester. A&P modules for this class 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): DSP introduces time and frequency domain analysis of digital signals, and digital filter design criteria for signal processing. Students design appropriate lowpass, bandpass, highpass and notch filters for denoising ECG signals corrupted by EMG activity and line noise. They learn spectral characteristics of these biological signals, as well as designing appropriate digital filters. They are also introduced to algorithms specifically designed for compressing biological signals. A&P modules 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 media. Students work in teams to build a biotelemetry system for transmitting noisy ECG/EMG /EEG signals. The system includes data acquisition, sampling, baseband digital modulation, bandpass modulation for transmission, detection and demodulation modules. A&P modules review neuronal conduction, similarities and differences among EEG/ECG/EMG, and the integumentary system as a vehicle for conduction of electrical signals.

8. Physiological Modeling (Control Systems): This class teaches basic control theory, and modeling strategies for closed loop systems. Students 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 then investigate the biodynamic control of respiration. They explore the effects of dead space (simulated by breathing through a tube) or exercise on tidal volume and frequency of breathing. A&P modules 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.

II. Technical Elective

A new technical elective is designed for senior level students who find the BME experiments interesting and stimulating, and therefore may wish to consider a career or graduate work in BME. Through the previous laboratory experiences all students will already have obtained a meaningful BME background by their senior year. Therefore this class is not just an isolated technical elective. The course, *Principles of Biomedical Systems and Devices (PBSD)* is intended to provide additional depth in such essential topics as 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 are also discussed, followed by a survey of more contemporary topics of clinical instruments for laboratory analysis and medical imaging systems, concluding with safety issues in design of biomedical equipment.

A design oriented mid-semester project and a final project serves as the laboratory components for this course. For the mid semester project, students work in groups on designing modules of a complete system, requiring them to combine their knowledge on various ECE, BME and A&P topics discussed throughout the four years of BME exposure. For the final project, they are asked to design an experiment that can be used to demonstrate some aspect of BME in future ECE classes. We hope that students will give us new ideas so that the experiments used in other ECE classes can be modified from year to year for more contemporary areas of BME.

RESULTS

Five of the laboratory exercises have been developed, implemented and assessed: measurements of basic biological signals (for Freshman Engineering Clinic I), reverse engineering of blood pressure monitor (for Freshman Clinic II), the cardiac / arrhythmia monitor (for Digital II); signal denoising (for DSP), and respiratory system monitoring (for Control Systems). We have also designed the experiments for Networks II and Electronics I, however these experiments are yet to be implemented by students. We have also developed, and twice offered the elective course.

Surveys were used as the primary tool for assessing the impact of the project on students' BME awareness and interest. The nature of individual classes allowed us to use different types of surveys. For example, in Digital II, DSP and Controls, we divided the class into two groups, target and control. Students in the target group participated in the BME related activities, but the same survey was given to both groups. In Freshman Clinic II and the BME elective, the entire class was BME related, therefore students were asked to evaluate the impact of the overall class in their interest to BME topics. Finally, in Freshman Clinic I, we were able to implement the experiment on three of the seven sections of the course, and conducted a full scale survey on all students. Due to space considerations, we present the more interesting single set of results from each group. More complete results will be presented later once remaining experiments are completed.

For the classes in the former group, students were randomly assigned into one of target or control groups. Only the target group participated in the BME experiments, and the associated A&P modules. The control group conducted another real-world experiment demonstrating similar ECE concepts, but not related to BME. An anonymous survey was given to both groups, where they were first asked to indicate the experiments they worked on, and whether – on a scale of 1 to 5 – they felt they have made the right decision by choosing ECE. These questions allowed us to identify the students in each group, and determine whether their answers would be biased due to some strong displeasure towards ECE. We then asked them to rate – on a scale of 0, 1 or 2, which of the 10 general engineering and 11 ECE related areas they would consider for graduate study or immediate career. One of these fields was BME. We also asked them to rank their interest in any of the 20 ECE related electives, of which three were BME related. An answer of "0" indicates no interest, "1" indicates some interest and "2" indicates very strong interest. Tables I and II list the results for each group for the Control Systems class. For each group, we calculated an overall BME interest factor for each student, as the normalized sum of all points given in Columns 3 (interested in BME?) through 9 (Career in BME?). The maximum normalized score of 1 is obtained if the student expresses strong interest in all BME related activities (strong interest in all BME classes, BME related graduate program, career, etc.). The true intent of the survey was concealed from students (to remove bias), by hiding all BME related items in a large number of other choices.

Tables I and II indicate that the students who were involved in a BME related experiment were more interested in BME, compared to those who did not. We would have liked to declare success by looking at these tables, and pointing out that the overall BME interest factor in the target group (0.39) is 60% higher than that of the control group (0.23). However, we refrain from doing so – at least for the time being – for the main reason that the standard deviations are rather high (perhaps due to low student count). A one-tailed t-test with unequal variances indicates that the target group has a higher BME interest factor with a p-value of 0.12 (88% confidence).

The results for the Freshman Clinic-I were, however, found to be statistically very significant. There were 7 sections of this class, taught by different professors, where different sections participated in different experiments. The seven sections included 134 students from four engineering programs at Rowan (ECE, Mechanical, Chemical, and Civil). Each section rotated through four programs (three weeks, three experiments in each program), where they were exposed to real-world experiments related to that department's field of interest. Three of the seven sections (n=47) have worked on the BME experiment described above (acquiring and measuring biological signals), as one of their three ECE experiments. These students were provided with an A&P module, were given brief information about BME in general, and how the experiment related to real life BME.

TABLE I . CONTROL SYSTEMS INDIVIDUAL SURVEY RESULTS - STUDENTS PARTICIPATED IN THE BME EXPERIMENT-

Satisfied with		Interested in BME ?		Interest in BME Related Courses			Graduate Study in BME ?	Career in BME?	Norm. Score BME Interest Factor
ENG	ECE	Within Eng.	Within ECE	PBSD	Medical Electronics	Medical Imaging			
3	4	1	0	1	1	1	1	1	0.43
4	4	0	0	0	0	0	0	0	0.00
5	5	1	1	1	1	1	1	1	0.50
5	5	0	0	0	0	0	0	1	0.07
5	5	0	0	0	1	0	0	0	0.07
4	4	0	0	0	0	0	0	0	0.00
4	3	1	1	1	1	1	1	1	0.50
5	4	1	1	1	2	2	1	1	0.64
4	4	1	2	1	2	1	1	2	0.71
4	5	2	2	2	2	1	2	2	0.93
								Mean	0.39
								St. Dev.	0.33

Table II CONTROL SYSTEMS INDIVIDUAL SURVEY RESULTS - STUDENTS DID **NOT** PARTICIPATE IN THE BME EXPERIMENT-

Satisfied with		Interested in BME ?		Interest in BME Related Courses			Graduate Study in BME ?	Career in BME?	Norm. Score BME Interest Factor
ENG	ECE	Within Eng.	Within ECE	PBSD	Medical Electronics	Medical Imaging			
4	4	0	0	0	0	0	0	0	0.00
5	5	2	1	1	1	1	1	1	0.57
4	4	0	0	0	0	0	0	0	0.00
5	5	0	1	2	1	0	0	1	0.36
5	5	0	0	0	1	0	0	0	0.07
5	5	1	1	1	1	1	1	1	0.50
4	4	1	1	0	0	0	0	0	0.14
3	4	0	0	0	0	0	0	0	0.00
5	5	1	1	0	1	2	1	0	0.43
								Mean	0.23
								St. Dev.	0.23

The remaining 87 students have also participated in a BME related experiment, however, not the one described in this paper, but rather an experiment on drug delivery and ECG measurement. Furthermore, these students were not provided with a similar A&P module or how experiments related to real world BME. A survey similar to the one described above was given to all 134 students. The results were very surprising and illuminating: the normalized average BME interest factor among the target group (n=47) who participated in the BME experiment described above (who were also taught an A&P module and briefed about BME), was 0.33 with a variance of 0.139. Among the control group (n=87) who also participated in a BME experiment – albeit a different one – without an A&P module, the average normalized BME interest factor was 0.184 with a variance of 0.05. A one-tailed two-sample test with unequal variances indicates that target group's BME interest factor is significantly higher than that of the control group with a p-value of 0.007 (about 99.3% confidence). This outcome is significant: merely exposing students to a BME related experiment does not increase their awareness or interest towards biomedical engineering, when the experiment is divorced from the underlying physiological concepts and how the experiment relates to the real-world problems.

Slightly different surveys were given to students in the elective course and Freshman Clinic II course, as all students were exposed to BME related concepts due to the nature of these classes. For the elective course, we conducted a pre-class and a post-class survey to assess the impact of the course in students' understanding and future interest in BME. In the first survey, they were asked to rate, on a scale of 1 to 5, whether they had any prior knowledge and/or work experience in BME, whether they were following popular media for BME related information and news, whether they had considered a graduate degree or a career in BME for the future, etc. All answers were added and normalized to 1 to obtain each student's pre-class BME interest factor. They were then asked to answer related but somewhat different questions in the second survey, such as to what extend the course raised their awareness for BME, whether they would take another BME class – if offered – based on their current experience, whether they feel their knowledge and experience after the class make them qualified for a BME related career, and how likely they were to pursue a BME related graduate degree or career. In order to account for differences in the number of questions in pre and post class surveys, all scores were first individually normalized to 1 and then averaged with respect to number of questions to obtain the post-class BME interest factor.

The pre-class BME interest factor of the entire class was 0.6 with a variance of 0.032, whereas the post-class BME interest factor was 0.87 with a variance of 0.049. A one-tailed two-sample t-test with unequal variances indicated that the

BME interest factor after the class was significantly higher, with a p-value of 0.00009 (99.991% confidence level).

We would like to mention an additional outcome – one we cannot measure statistically – but perhaps emotionally the most satisfying indicator of the impact of this project. Since the start of this project, we had four students who have pursued a BME related graduate study and/or career upon graduation, even though they only had a two-year exposure to BME within this project. Four students may seem very few, however, we believe it is significant, since no other Rowan Engineering student has ever followed a similar path since the start of the engineering program in 1995.

CONCLUSIONS

We proposed a new model specifically designed to integrate novel content material into the existing curriculum. The model uses 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 as the novel content, due to its rapidly growing nature and future job opportunities it presents, and electrical and computer engineering as the core curriculum due to our primary background. Our primary objective was to raise awareness and interest in an emerging area, and facilitate the efforts of those students who may wish to pursue future graduate school or career opportunities in BME related fields.

This approach has several advantages: (1) it is versatile, any number of topics that the faculty deems important can be used as novel content; (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 well-rounded and broad education within their specific disciplines; (6) experiments are integrated into existing courses, keeping credit count unchanged; and (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.

Initial outcomes are promising, and indicate that the approach has strong potential of success. We also have some specific conclusions, however: our experience with the Freshman Engineering Clinic I class demonstrates that a BME experiment does not - on its own – elevate students' awareness and interest, unless it is complemented with appropriate A&P background, and unless students are shown how the experiments relate to real world job experience of biomedical engineers. Furthermore, students are more likely to pursue a graduate degree or a career in BME if their experience is enhanced by an elective class that provides additional depth and a unified background to many of the topics they had seen during the previous experiments.

Among the lessons we have learned, two are most noteworthy: First, it is important to have the support of the entire department, as each instructor must be willing to use some of their laboratory time for such an initiative. Second, while the specific nature of the experiments is less important, the connection of these experiments to the real world, and the underlying A&P concepts are crucial, and must be provided to the students.

While it is too early to make overall generalizations on the success of the approach, we are very encouraged with the promising results; not only with the elevated levels of BME interest in students who participated in the BME experiments and the elective, but also in the significant jump in our seniors going to BME related graduate programs.

ACKNOWLEDGMENT

This material is based upon work supported by the National Science Foundation under Grant No. DUE-0231350

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