# AC 2007-463: INTRODUCING MULTIDISCIPLINARY NOVEL CONTENT THROUGH LABORATORY EXERCISES ON REAL-WORLD APPLICATIONS

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# Introducing Multidisciplinary Novel Content through Laboratory Exercises on Real World Applications

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**Abstract:**
One of the primary missions of any engineering program is to provide a well-rounded education that combines all fundamental concepts of the given area with an adequate exposure to relevant contemporary areas. However, the exponentially growing body of knowledge – particularly in emerging areas of engineering sciences – makes this mission an increasingly challenging proposition. More novel content from emerging areas need to be integrated into the curriculum to ensure that our students can be successful in today's competitive job market. On the other hand, the economic and political realities of today's academic environment restrict the number of credits a program can require for degree completion. The challenge, then, is to be able to provide as much meaningful and cohesive exposure to emerging / contemporary areas without sacrificing the fundamental background while keeping the credit count minimally effected, or preferably, unchanged.

We have previously reported the preliminary assessment of our proposed approach, which consists of reconfiguring a time-honored teaching tool to integrate novel content into existing curriculum. We developed laboratory exercises distributed over the entire four year curriculum, which were integrated into existing core and elective courses. The exercises were designed to provide multidisciplinary novel content in emerging areas that relate to focus areas of existing courses. In our implementation, we use bioengineering/biotechnology (BME) as the multidisciplinary emerging topic area, and electrical/computer engineering (ECE) as the core curriculum. Since our initial report two years ago, which was based on a couple of experiments, we have developed several new laboratory exercises, and more importantly followed students who went through the four years of integrated BME content. In this paper, we present our implementation and assessment details, and some surprising outcomes we have observed since our previous preliminary assessment. We discuss many advantages, but also some potential pitfalls of this approach, along with lessons learned along the way.

## 1. Introduction

Thanks to increased world-wide support to research and development, there has been a tremendous growth in the scientific and engineering body of knowledge. Such knowledge allows us to solve increasingly challenging and complex problems that cross the boundaries of traditional disciplines. An efficient solution of such problems, however, requires the synergistic combination of expertise in multiple areas. Consequently, students graduating from today's engineering programs can no longer be competitive in tomorrow's job market, by having a strong background only in their specific chosen areas of study. They need reasonably adequate exposure and background in relevant emerging areas as well. Only then, they will be equipped with the necessary skills to quickly acquire expertise in a new area demanded by their current position. As engineering educators, our challenge is to be able to provide them with an educational experience that not only provides a thorough background of their chosen field, but also a meaningful exposure to relevant multidisciplinary emerging and contemporary areas.

The benefits of introducing multidisciplinary content into an existing curriculum have already been well-established, and many engineering programs have recently started integrating such content into their curriculum. Traditionally, such topics are introduced through electives or seminar courses. While electives and seminar courses are indispensable tools, providing novel content through such courses has its inherent limitations, including but are not limited to:

- very few (typically one) electives / seminar courses are offered in any given area;
- since only limited amount of material can be covered in a single course, either depth or breath (or both) must be sacrificed;
- students who have not been exposed to the topical area previously may feel hesitant in electing such a course.

Furthermore, given the current economic and political realities, restricting the number of credits that can be required to earn an engineering degree, there is often little room in the curriculum for electives, further restricting the amount of multidisciplinary exposure that students can have in emerging areas.

We have recently proposed a laboratory based solution to this problem, where the novel content is introduced – over the course of four years – as applications in the laboratory exercises of the classes with the closest topical areas within the existing curriculum. Unlike the short (usually single) term exposure provided by an elective, the long term exposure of the novel content, distributed over four years, allows us to provide a meaningful balance of breadth and depth. In our implementation, we use bioengineering/biotechnology (BME) as the multidisciplinary topic area due to reasons described in the next section, and electrical/computer engineering (ECE) as the core curriculum due to our background in this area. We have two specific objectives in our approach: to introduce ECE students to this fast growing field by providing them with contemporary BME exposure; and to improve their comprehension of ECE topics by relating these topics to real world problems in medicine.

We first described this approach, along with our initial assessment based on our implementation outcomes on a couple of courses two years ago[1]. Since then, we have implemented this approach on several additional courses, realizing its many advantages, but also some pitfalls along the way. In this contribution, we describe the approach in greater detail along with its strengths, its implementation, new outcomes since our last report, as well as some lessons learned during our experience. Specifically, we first discuss our reasons for choosing BME as the novel content area in Section 2, followed by our specific goals and objectives in Section 3. The implementation details of the proposed approach are discussed in Section 4. We then describe our assessment methodology, and the associated results and outcomes in Section 5. The advantages and potential pitfalls of the approach, and the lessons learned along the way, are discussed in Section 5 in our concluding remarks.

## 2. Biotechnology and Biomedical Engineering as Emerging Areas of Engineering

There are several emerging areas that cross the traditional boundaries of engineering disciplines, including biotechnology, nanotechnology, green engineering and sustainable design, among many others. Each of these areas has already made a significant impact in our daily lives, and continues to do so at a rapidly growing rate. In this pilot study, we have chosen to focus on biomedical engineering due to several reasons discussed below; however, as we describe later in this paper, the proposed approach can be used to integrate any novel content (or more than one) into any of the traditional engineering disciplines.

Biomedical engineering (or bioengineering – BME) is one of the fastest growing areas in the US – not only among engineering sciences, but also among all major areas of industry. The U.S. Department of Labor (DOL) cites increasing public concern for well-being, as well as the aging population in the US, as factors that intensify the focus on health issues, which then drives the demand for better medical devices, equipment and processes designed primarily by biomedical engineers[2]. As of October 2006, the Bureau of Labor Statistics within DOL estimates that the job market for biomedical engineers will increase about 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% [2,3]. 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[3]. Therefore, the job growth rate may be even faster than the above mentioned estimate. 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[4]. In fact, only 36 of these institutions offer an accredited undergraduate BME degree program[5]. 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[6]. The result is therefore an increasing gap between the demand for qualified BME professionals, and available programs for educating them, causing a potentially significant, yet unmet, national need.

This unmet need has not gone unnoticed, as indicated by the sharp increase in the number of degree programs in biomedical engineering. While smaller in number, new undergraduate programs in BME have also recently opened their doors. For example, University of California, Los Angeles, has just started accepting students into its new bioengineering program. There has been an overwhelming interest in the new program with over 2000 applicants for a mere 35 seats[7], indicating a growing BME interest among nation's high school seniors.

However, creating a new program is a major undertaking that requires significant resources and a substantial investment that is beyond the reach of most institutions even during the best of economic times. Furthermore, The Whitaker Foundation – the most influential supporter of new BME programs in recent times – recently shut itself down in June 2006 after investing $720 million in 30 new bioengineering departments. While increasing the capacity of the existing programs is also an option, such an approach is only incremental and geographically restricted in nature. Hence, we choose BME as the emerging area, so that our students can also obtain a reasonable background in BME, in addition to their traditional ECE education, and perhaps contribute – however little it may be – to the above described national need.

## 3. Overall goals and objectives

We would first like to emphasize that we are faced with 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 emerging and rapidly developing fields of study for which there is significant unmet demand. On the other hand, these issues cannot be fully addressed by simply opening new degree programs, due to the enormous cost associated with creating such programs. Furthermore, while opening new programs can help us expand a specific emerging field to a wider audience, it cannot help students in other programs expand their horizon. Also, the courses offered in a new program are themselves restricted to the topical contents of that area, which will eventually lose its *emerging* status, and become a rather established area. It is not flexible enough to deliver different novel contents as they emerge. Electives and seminar courses do provide such flexibility; however, they have their own shortcomings as discussed earlier. Therefore, we need to consider innovative solutions, as a complementary approach to electives and seminars.

Our ultimate goal is of course to develop such an approach that will allow us to provide a better-rounded engineering education by exposing students to emerging topical areas through their existing curriculum. We envision this approach to serve as a prototype that can potentially be used as a national model primarily by engineering colleges and departments that would like to provide novel multidisciplinary content for their students, but lack the necessary resources to provide a full-fledged degree program, and/or to offer a wide spectrum of electives.

We also have two specific objectives under this overarching goal:

- expose all ECE students – and raise their awareness – to emerging biotechnology topics by providing them with essential and contemporary BME knowledge; and
- to enhance their comprehension of core ECE concepts by applying such concepts to multidisciplinary real world problems in medicine.

Integrating such novel content into an existing core curriculum, we believe, can not only help us achieve these objectives, but also allow us to do so with very little or no additional resources. The proposed approach is essentially to develop a set of experiments, designed to demonstrate novel concepts, integrated into select core curriculum courses, to complement any electives that may be offered in such an area. In our case, we designed the experiments to expose students to various BME concepts and associated relevant topics of underlying physiology, and integrated them into core ECE courses, distributed over four years. Our first objective is therefore achieved by exposing students to a wide selection of BME topics through carefully designed experiments demonstrating both ECE and BME concepts. The experiments are distributed throughout the ECE curriculum, providing a 4-year, continuous exposure of BME topics. We then complement such exposure with a new senior elective course providing a more comprehensive and in-depth BME overview, for those students who realize – as a result of this long-term exposure – that they would like to learn more about this field.

Our second objective, on the other hand, is mostly of pedagogical value: exposing students to multidisciplinary concepts, particularly when accompanied by appropriate hands-on laboratory experience, has been shown to improve students' 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] . Towards this objective, we strategically select 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[13-18]. The human body provides "a theme" as an excellent example for such a familiar system.

Finally, we would like to emphasize that our proposed approach is by no means a substitute for a full-fledged degree program, nor is it intended to be one. It is simply using a well-established academic tool (laboratory exercises) in a new setting to expose students to emerging areas using only modest resources. We believe that the true benefit of this approach is in fact its flexibility and agility: while we have used BME and ECE as novel and existing areas, respectively, the approach can easily be modified and implemented by any engineering program, on any novel content – and then be updated for other emerging areas as they appear – simply by suitable choice of experiments.

## 4. Implementation

Our proof-of-concept implementation of the proposed approach includes a total of eight experiments to be incorporated into the ECE core curriculum, along with a new technical elective with its own project(s). Depending on the specific class and the complexity of the particular laboratory exercise, the experiments can take anywhere from 1 week to an entire semester of 15 weeks.

We should re-emphasize that an important objective of our effort is to provide a broad background in biomedical engineering, and it is not just conducting random experiments as applications of electrical engineering in medicine. Such a broad background cannot be obtained if the engineering knowledge to be gained is divorced from the underlying and enabling anatomy and physiology. Therefore, a portion of the time available for each experiment has been set aside for "Anatomy & Physiology (A&P) Modules" to discuss the underlying anatomy and physiology concepts relevant to the experiment. These modules are typically taught by a faculty member from the Department of Biological Sciences.

The experiments designed for this project are described below, along with the class for which they are designed, and the targeted ECE and BME concepts to be learned. In all experiments described below (unless noted otherwise) students acquired their own biological signals using medical grade isolated biopotential amplifiers, adding an additional dimension of *real-worldliness* to these exercises.

### 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 measurements[19]. 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 as they compare the effects of gender, fitness, weight, and smoking habits on these parameters. In the A&P modules for this exercise, students are introduced to very essential concepts and terminology of cardiovascular and respiratory physiology. Through the use of an isolated biopotential amplifier for acquiring data, students are also exposed to the ECE concepts of signal amplification, noise filtering, sampling and analog to digital conversion.

**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 engineering[20]. Students reverse engineer and comparatively assess competing automated blood pressure monitors. They 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 that are 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 concentrate on cardiovascular dynamics, particularly the cardiac cycle and pressure/volume relationships, as they relate to blood pressure.

**3. Basic Amplification & Filtering – (Networks I & II):** This sequence of classes, taught back to back in one semester, teach analysis of resistive, capacitive and inductive circuits, including how they can be used to build basic amplification 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 origins of biopotentials, membrane potentials, action potentials, and transmission of such potentials within the nervous system.

**4. Biopotential Amplifiers (Electronics I):** Electronics I introduces basic electronic components and amplifier design strategies. We have designed two 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 other 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 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 II is concerned with logic circuit design and applications of microprocessors. In this course, the laboratory experiments are designed as semester long projects, where students work on different projects in teams. 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, and it is used as an intermediate milestone in assessing students' interest in BME. 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 (Digital Signal Processing):** 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 for analyzing random signals and spectral estimation of such 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 techniques. Students work in teams to build a biotelemetry system for transmitting noisy ECG/EMG/EEG signals. The system includes the modules of data acquisition, sampling, baseband digital modulation, bandpass modulation for transmission, detection and demodulation of the signal. A&P modules 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 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) on tidal volume and frequency of breathing empirically, and effects of exercise on the respiratory system. 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.

### B. Technical Elective: Principles of Biomedical Systems and Devices

A new technical elective, taught during the senior year, has been developed for students who find the BME topics interesting and stimulating, and therefore wish to consider a career or graduate work in BME. All students will already have obtained some prior BME background and motivation by their senior year, and therefore this class will not be just an isolated technical elective. The course first reviews 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 are then discussed, followed by a survey of more contemporary topics of clinical instruments for laboratory analysis and medical imaging systems, concluding with a broad discussion of 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. Students are given design specifications that are relaxed enough to ensure that the project can be completed within a semester, yet realistic enough to demonstrate the intended concepts. 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 dynamically modified from year to year and students may be exposed to more contemporary areas of BME.

**5. Results**

Previously, we have reported the results of our initial implementation on two experiments and the elective course. Since then we have completed additional experiments and offered the elective course for a second time for a total of six BME related experiences. In this section, we first describe our survey based quantitative assessment tool, followed by the results – including statistical analysis of these results – obtained using these tools.

Our primary goal with the assessment was to determine whether these BME experiences did in fact raise the students' awareness, and increased their interest and knowledge in BME. For all classes we used carefully designed surveys as our primary tool of quantitative assessment – however, due to differences in the nature of the courses, the same survey could not be used in all classes. For most classes, we have divided the class into two groups, where one of the groups served as the *target group*, and the other served as the *control group*. Only the target group participated in the BME related activities of that class. In other words, the students in the control group did not take the A&P module, and did not complete the above described experiment for that class. Instead, students in these groups completed the regularly scheduled experiment for that class, which were still related to the same ECE concepts, but on non-BME related applications. The same survey, described below in more detail, was given to both groups, which was designed to obtain a measure of post-class overall BME interest factor. We then compared the two groups to determine whether the overall BME interest factor was higher for the students who participated in the BME experiments than those who did not. As we also discuss below, the survey was designed to hide the parameter it was trying to measure, so that student bias could be minimized as much as possible.

The anonymous survey used for those classes with a target and control group was designed as follows. The students were first asked to indicate the experiments they worked on. Since the surveys were anonymous, this allowed us to determine whether each survey participant was in the control or the target group. The survey then asked, whether – on a scale of 1 to 5 – they felt they have made the right decision by choosing engineering in general and Electrical and Computer Engineering in particular, and whether they feel they have learned a substantial body of knowledge thus far in their classes. These questions allowed us to determine whether their answers would be biased due to some strong displeasure towards engineering or ECE. The survey then asked them to rate – on a scale of 0, 1 or 2, which of the 9 general engineering and 10 ECE related areas they find most interesting based on what they have seen thus far in their college education. One of the 9 general engineering fields, and one of the 10 ECE related areas was biotechnology / biomedical engineering. The survey also asked them to rank their interest in each of the 20 ECE related electives, and whether they would take them if offered. Three of the 20 courses were BME related (principles of biomedical systems and devices, medical electronics and medical imaging). The remaining list included courses representing several other emerging areas that are related to ECE as well as more traditional ECE areas. Finally, in two separate questions the survey listed again those 10 areas related to ECE mentioned in the earlier questions, and asked students to indicate whether they would be interested in pursuing each of those areas for an immediate career, or for a graduate degree. The students were asked to rank each area on a scale of 0 – 1 – 2. In all questions using the 0 – 1 – 2 scale, an answer of "0" indicated no interest, "1" indicated some interest and "2" indicated very strong interest.

As an example, Tables I and II list the results for each group for the Control Systems class. For each group, we then calculated an overall BME interest factor for each student, as the normalized sum of all points given in Column 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 normalized BME interest factors of the two groups were then compared to each other – not just by looking at the average values, but also through appropriate statistical tests to determine whether there was any statistically significant difference between the two groups. Since our goal was to compare the target and control groups, we have only analyzed the BME interest factor, and did not compute such a parameter for any of the other areas. After all, the two groups differed only in that one experiment in which they participated.

We would like to note that, in constructing this survey, we had three major objectives: (1) determine the true BME interest the experiments may have produced in students, (2) test this interest in more then one way by asking similar questions multiple times – but in slightly different forms, and most importantly (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. For example, in asking which of the 10 ECE related areas students considered for future career, we were really interested whether they would include BME in their list, and if so how strongly? None of the questions blatantly asked whether the experiments had any impact in their BME interest. The questions were completely neutral to all areas of engineering / ECE.

One may argue that because the questions are related, they all test more or less the same thing. This was intentional: 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. Control systems individual survey results – target group

| Satisfied with | | Is BME interest included…? | | Interest in BME Related Courses | | | Graduate Study in BME ? | Career in BME? | Normalized BME Interest Factor |
|---|---|---|---|---|---|---|---|---|---|
| ENG | ECE | Within Engineering | 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 2. Control systems individual survey results – control group

| Satisfied with | | Is BME interest included…? | | Interest in BME Related Courses | | | Graduate Study in BME ? | Career in BME? | Normalized BME Interest Factor |
|---|---|---|---|---|---|---|---|---|---|
| ENG | ECE | Within Engineering | 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 |

In the Control Systems I class, the students were randomly split into two approximately equal size groups, target ($n_T$ =10) and control ($n_C$=9), where the target group conducted the BME experiment, whereas the control group conducted a similar experiment but with other (non-BME related) application. The mean normalized BME interest factors in Tables 1 and 2 indicate that the students in the target group who participated in a BME related experiment were more interested in BME, compared to those who did not. We would have liked to declare a major success by looking at these tables, and pointing out that the overall BME interest factor in the target group ($\mu_T = 0.39$) is about 70% higher than that of the control group ($\mu_C = 0.23$). 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. This means that the difference is statistically significant with an 88% confidence. In other words, there is only a 12% probability that the difference between the groups is merely due chance: had we made a different random sampling of students while putting them in target vs. control groups, there is a 12% probability that we would not have seen the same outcome. This result gives us 88% confidence that the difference we see between the two groups is not due to chance, but in fact due to the actual control factor, that is, due to one group of students being exposed to BME related areas. While the 88% confidence may seem reasonably good, the standard confidence commonly accepted by statistical communities is 90%, or even better if it is 95%.

A similar result was obtained in the Digital II course, where the average normalized BME interest factor for the target group ($n_T$=6) was $\mu_T$=0.46 with a standard deviation of $\sigma_T$=0.41, whereas that of the control group ($n_C$=11) was $\mu_C$=0.22 with $\sigma_C$=0.34. In this case, the BME interest factor of the target group is more than twice that of the control group, however the standard deviations are also high. The two-sample t-test with unequal variances revealed that the target group's factor was statistically higher than that of the control group with a p-value of 0.127, that is, a confidence of 87.3%

In the Networks I/II class, the average normalized BME interest factor for the target group ($n_T$=11) was $\mu_T$=0.54 with a standard deviation of $\sigma_T$=0.32, whereas that of the control group ($n_C$=8) was $\mu_C$=0.22 with $\sigma_C$=0.18. According to these numbers, the students in the target group had a BME interest factor that was almost two and half times (i.e., 250%) that of the control group. A t-test then shows that this difference is statistically very significant with a p-value of 0.0067, that is, a confidence level of 99.3%. These results indicate that a single BME related experiment had a very significant impact on student's awareness and interest in BME.

In the DSP class, the average normalized BME interest factors for the target group ($n_T$=14) was $\mu_T$=0.48 with a standard deviation of $\sigma_T$=0.29, whereas that of the control group ($n_C$=13) was $\mu_C$=0.26 with $\sigma_C$=0.27. A t-test indicated that this difference is also statistically very significant with a p-value of 0.01, that is, a confidence level of 99%.

Perhaps one of the most interesting results came from the Freshman Clinic I class. This is because we had access to a much larger student body to conduct the experiments as well as the surveys. 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 all four engineering programs at Rowan (Electrical and Computer, Mechanical, Chemical, Civil and Environmental). Each section rotated through four programs (three weeks, three experiments in each program), where they were exposed to experiments related to that department's field of interest. Three of the seven sections ($n_T$ = 47 students) 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 biomedical engineering in general, how the experiment related to biomedical engineering, and what they could expect to do if they later decide to pursue a BME related career. The remaining ($n_C$ = 87) students have also participated in a BME related experiment (not the one described in this paper, but rather an experiment on drug delivery and ECG measurement), however, these students were not provided with an A&P module or any information on biomedical engineering.

The results were very illuminating: the normalized average BME interest factor among target group students who participated in the BME experiment described above (who were also taught an A&P module and briefed about BME ), was $\mu_T$ = 0.33 with a variance of $\sigma_T$ =0.139. Among the control group, who also participated in a BME experiment –albeit a different one – and without an A&P module, the average normalized BME interest factor was $\mu_C$ =0.184 with a variance of $\sigma_C$ =0.05. The two-sample t-test with unequal variances indicated that the 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, because it indicates that 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 field of biomedical engineering.

The structure of certain classes did not allow us to use such a controlled-group-based survey, however. Specifically, classes where all students participated in a BME activity due to the nature of the course, such as the elective course on Principles of Biomedical Systems and Devices (PBS&D), did not have a control group. We have therefore used a pre-class and a post-class survey to determine the impact of class in their understanding and appreciation and future interest in the BME field.

The pre-class survey asked students to indicate their interest and plans in various BME related activities, such as their interest in following popular and academic media on BME topics, their interest in taking other BME related courses, and their interest in future BME careers and/or graduate school. Their answers were normalized and averaged to obtain a pre-class BME interest factor. Similar questions were also asked in the post class survey, along with additional questions on whether they felt the class raised their interest, awareness, knowledge and skills in BME. All answers were normalized with respect to the number of questions, so that the additional questions in the post-class survey would not add any bias to the results. Since this class was specifically on BME, there was no reason to hide the BME content of the survey, as in the previous cases. The normalized and averaged scores were then obtained as the post-class BME interest score. The pre and post-class BME interest factors were then compared to each other, again, using appropriate statistical tests to determine whether there was a statistically significant difference between the before and after class interest factor in BME.

The pre-class BME interest factor of the entire class was $\mu_{PRE} = 0.6$ with a variance of $\sigma_{PRE} = 0.032$, whereas the post-class BME interest factor was $\mu_{POST} = 0.87$ with a variance of $\sigma_{POST} = 0.049$. A 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).

Finally, we would like to share one additional outcome – one that we cannot measure statistically – but perhaps professionally the most satisfying indicator of the impact of our efforts. Since the start of this project, we had five students who have actually pursued a BME related graduate study and/or career upon graduation, even though they only had a two-three year exposure to BME within this project. Five students may not seem very many; 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.

## 5. Conclusions & Discussions

We described a model specifically designed to integrate novel content into the existing curriculum. This model involves developing 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.

The quantitative survey results indicate that students who participated in the BME related activities had much increased awareness and interest, and therefore more likely to pursue a career / graduate study opportunity in this area. In all classes where we implemented this approach, the BME interest factor of those students participating in the BME experiments were always higher, and often with statistically very significant and wide margins.

The approach has several advantages: (1) first and foremost, it is versatile: any number of topics, not only BME related, 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 (admittedly, however, during our proof-of-concept studies not all students participated in all activities, as some were in control groups who followed the standard laboratory experiments); (4) very little additional resources are required for implementation; (5) students receive a well-rounded 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.

In general, we conclude that initial outcomes indicate that the approach has strong potential of success in the long run. However, to ensure success, certain key issues must be addressed. 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. This is not always trivial, as some professors may not have the flexibility to accommodate a separate experiment in their courses due to the structure of their course. 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 still too early to make sweeping generalizations on the success of the approach, 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 and the BME elective, but also in the significant jump in our seniors going to BME related graduate programs. Our longer-term plans include developing not only additional BME related experiments and technical electives, but also expand this idea to other areas of emerging topics, such as nanotechnology, sustainable design, green engineering, etc.

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