Integrating BME into ECE Curriculum: An Alternate Approach for

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Abstract:

A time honored technique for introducing students to new and emerging topics is to offer electives; however, there are a few major drawbacks to this approach: the topic must be very focused, either depth or breath must be sacrificed, and in either case, only a very limited amount of material can be covered, and students who may not have prior background about the topic often hesitate in electing a course in which they may very well find interest. Furthermore, as the number of credits required for obtaining a BS degree decline over the years due to market pressures, so do the number of electives offered.

Against this background, we propose another time-honored technique, under a new setting, as a paradigm specifically designed for integrating novel content material into existing curriculum: develop new laboratory exercises tailored to provide content specific knowledge that relate to the focus areas of existing courses. In our implementation, we use biomedical engineering (BME) as the novel content and the electrical and computer engineering (ECE) as the core curriculum, with two primary objectives: to provide ECE students with fundamental and contemporary 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. 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; (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.

In this paper, we present the details of our implementation, the specific topics targeted, the experiments designed and our one-and-half-year implementation outcomes.

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 26.1%, faster than the average of all occupations, through 2012. This is almost double the overall job growth rate of 15.2% and almost three times the overall growth rate of 9.4% for all engineering jobs[1,2]. According to 2002 figures, there are about 7,600 biomedical engineering jobs in the United States, which is expected to exceed 10,000 by 2012[1,2]. However, BME education, more specifically, the seats available for BME undergraduate education, has not kept pace with this rapid growth and development. There are about 130 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 33 of these institutions offer an accredited undergraduate BME degree program[4] .

The situation does not appear to be too bright for BME, when we look at the numbers of degrees conferred, despite recent growth. 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 BME[5]. 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, and some schools do exactly that: University of California, Los Angeles (UCLA), 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 daunting task that requires significant resources and a substantial investment, which is difficult to attain even during the best of economic times. Furthermore, considering that The Whitaker Foundation, the major supporter for new bioengineering programs – with over $720 million for 38 new bioengineering departments – shutting down in 2006, creating 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, integrating multidisciplinary novel content into an existing core curriculum may be a viable solution by providing students with fundamental background and knowledge on the novel content, while requiring little or no additional resources. This paper describes such an approach by using multidisciplinary BME topics as the novel content and the electrical and/or computer engineering (ECE) curriculum as the existing core discipline.

The approach is essentially to develop a set of experiments, designed to demonstrate fundamental BME concepts and associated relevant topics of underlying physiology, integrated into select ECE core courses, along with a new senior elective course providing a comprehensive BME overview. We have selected ECE as the base curriculum primarily due to our own expertise in this field. However, the approach described in this paper can easily be modified for other engineering programs, on any novel content, by suitable choice of experiments.

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, since it can be easily implemented by any one of nation's over 300 electrical, 270 mechanical, 160 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. We first reported the preliminary outcomes during 2004 ASEE Annual Conference and Exposition[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.

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. Our two objectives under this goal are (i) to provide essential and contemporary BME knowledge for all of our ECE students and (ii) to enhance their comprehension and motivation through applications of learned ECE concepts in multidisciplinary real world problems in medicine.

Our first objective is intended to raise awareness of the biomedical engineering field, provide exposure to an additional multidisciplinary topic, and enable those to may wish to pursue career or graduate education opportunities in BME related fields. Towards this objective, we propose to expose students to a wide selection of BME topics through carefully designed experiments demonstrating both ECE and BME concepts. For students who express interest in BME, the concepts learned through the experiments are complemented by 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.

Our second goal 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.

Our long-term vision for the full development of this project is the complete integration of a full spectrum of BME – and later other novel and contemporary topics such as nanotechnology – into the entire ECE curriculum, with additional elective courses designed to provide a minor or concentration in the novel content area. 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

The proposed prototype includes eight experiments to be incorporated into the ECE core curriculum, along with a new technical elective with its own project(s) to achieve the above stated goals and objectives. Depending on the specific class, the experiments can take anywhere from 1 week to 15 weeks. 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 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 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 effect of gender, fitness, weight, 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. 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 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 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 us used as an intermediate milestone in assessing students' interest in BME. Only a portion of students are assigned the BME experiment, whereas the rest continue to work on non BME related laboratory exercises. A&P modules for this class, provided to all students whether they participate in a BME experiment or not, 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 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 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 acquisition, 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 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.

3.2 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 may wish to 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 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 be 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.

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 measurements of basic biological signals (for Freshman Engineering Clinic I), on reverse engineering of blood pressure monitor (for Freshman Engineering Clinic II), the cardiac / arrhythmia monitor (for Digital II) and signal denoising (for Digital Signal Processing). We have also designed the experiments on biopotential amplifiers (for Electronics I), and respiratory system modeling (for Control Systems) however these experiments have not yet been implemented by students. We have also developed and twice offered the elective course, Principles of Biomedical Systems and Devices. The course had a considerable interest from students in its initial offering, as twenty-two students signed up for the course, who represented about 80% of our senior population. Student evaluations indicated that all students immensely 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. Due to the overwhelming interest, the course was offered again during Fall 2004, and students' pre and post-class interest in BME has been assessed via a series of surveys, as described below. Out of 14 students who have taken the course during its second offering, two have indicated that they are / will be applying to graduating programs in BME and that they are committed towards a career in BME. These numbers may seem small but they represent a very significant change, as none of our graduates – since our first graduating class in 2000 – has ever applied to a BME graduate program before and/or worked on a BME related graduate research project prior to the implementation of our approach.

We have conducted several surveys on students who have been exposed to BME topics through this approach.

For Digital II class, a random portion of the students 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 strong displeasure towards engineering or ECE in general. We then asked them to rate – on a scale of 0, 1 or 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 some interest and "2" indicates a strong interest. Table I for 6 students who were involved in the BME experiment, and Table II for 11 students who were not, summarize the outcome of this survey. We have then calculated an overall *BME interest factor* for each student, as the normalized sum of all points given in Columns 3 (interested in BME?) through 8 (Career in BME?). The maximum normalized score that can be attained is one, 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 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 then 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.

One may argue that because the questions are related, they all 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 I. Survey results of students who did participate in a BME related project

				Participated in a BME Experiment				BME interest factor
Satisfied with			**Courses**					
ENG	**ECE**	**Interested in BME ?**	**PBSD**	**Medical Electronics**	**Medical Imaging**	**Graduate Study in BME ?**	**Career in BME?**	**Norm. Total Score**
4	4	0	1	1	1	1	1	0.42
5	5	1	2	2	2	1	2	0.83
4	2	0	0	0	0	0	0	0
4	4	1	1	1	1	1	1	0.5
3	3	2	2	2	2	2	2	1
4	4	0	0	0	0	0	0	0
							Mean	**0.46**
							St. Dev.	**0.41**

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

Satisfied with		Did NOT Participate in a BME Experiment						
		Interested in BME ?	Courses			Graduate Study	Career in BME	BME interest factor
ENG	ECE		PBSD	Medical Electronics	Medical Imaging			
4	5	0	0	0	0	0	0	0
4	4	0	0	1	0	0	0	0.08
5	5	0	0	0	0	0	0	0
3	3	2	1	1	0	0	0	0.33
3	3	0	0	1	1	1	1	0.33
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	1
5	5	1	0	2	1	2	2	0.66
							Mean	**0.22**
							St. Dev.	**0.34**

Tables I and II 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 (0.46) is more than double that of the latter group (0.22). However, we refrain from doing so – at least for the time being – for the main reason that 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 two-sample t-test).

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.

We have conducted a similar survey for the Freshman Engineering Clinic I class, whose results were found to be statistically significant, as described below. There were 7 sections of this class, thought 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 (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 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 information on biomedical engineering.

The survey was conducted on all 134 students, where they were first asked, on a scale of 1 to 5, whether they thought they made the right decision by choosing engineering in general, and their chosen major in particular, as described for the Digital II survey. They were then asked to chose – on a scale of 0 (no interest), 1 (some interest) or 2 (strong interest) various areas of engineering in which they now feel that they are interested. One of these areas was biomedical engineering. The score the student gave to BME (0, 1, or 2) was noted. They were also asked to choose the top three (of the 12) experiments from which they felt that they have learned the most and therefore may pursue such relevant areas in the future. If the BME experiment was in their top three list, an additional "1" point was added to that students BME score from the previous question. The total was then normalized to 1 to obtain the normalized BME overall interest indicator for each student. Due to large number of students, we do not list the complete table of responses as the Digital II surveys, but rather provide the statistical summary of outcomes.

The result was quite surprising and very illuminating: the normalized average BME interest factor among the first group students (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 second group (n=87) who also participated in a BME experiment –albeit a different one – without an A&P module and with no briefing on biomedical engineering, the average normalized BME interest factor was 0.184 with a variance of 0.05. We have first conducted a two-tailed, two-sample test (with unequal variances) to determine whether we could statistically claim that the two groups have *significantly* different BME interest factors. We found that we can indeed do so with a p-value of 0.014 (about 98.5% confidence, higher then the standard 95% confidence typically used in such tests). We have also conducted a one-tailed two-sample test (with unequal variances) to determine whether we can statistically claim that the first group's BME interest factor is *significantly higher* then that of the second group. We have found out that we can do so with even a greater confidence: 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 field of biomedical engineering.

Finally, we have also conducted a series of two surveys to the seniors who took the elective, Principles of Biomedical Systems and Devices. One survey was given at the beginning of the semester to determine their pre-class interest in BME, and the second was given at the end of the class to determine their post-class interest in BME. Our goal, of course, was to assess whether the class had any positive impact on their interest in biomedical engineering. In the first survey, they were asked to rate on a scale of 1 to 5, whether they thought they have made the right decision by choosing engineering in general and ECE in particular, 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 would consider a graduate degree or a career in BME in the future. All answers were added and normalized to 1 and averaged to obtain each student's pre-class BME interest factor, which were then averaged again with respect to the number of students to obtain entire class' overall pre-class BME interest factor. They were then asked to answer, again on a scale of 1-5, similar but somehow different questions in the second survey: whether the course raised their awareness for biomedical engineering, whether they would take another BME class - in offered – based on their experience in this class, whether they feel their knowledge and experience after the class make them qualified for a BME related career, whether they are now more likely to follow popular media for BME related information and news, and whether they are now (after the class) were likely to pursue a BME related graduate degree or a career in BME. 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 for each student, and then that of the entire class.

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. Again, we conducted two-tailed and upper-tailed two-sample t-test (with unequal variances). We found that the class had significantly different BME interest factors before and after the class with a p-value of 0.0002 (99.98% confidence level), and that the post-class BME interest factor was significantly higher then the pre-class BME interest factor with a p-value of 0.00009 (99.991% confidence level).

5. Conclusions & Discussions

We are currently working on a 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. We have chosen BME as the novel content due to significantly growing gap between the need for qualified BME professionals and actual number of students graduating with such qualifications, and we have chosen ECE as the core curriculum due to our expertise in this area. This approach has several advantages: (1) 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; (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.

In general, we conclude that initial outcomes indicate that the approach has strong potential of success in the long run. We also have some specific conclusions, however: our experience with the Freshman Engineering Clinic I class indicate that a BME experiment does not - on its own – elevate students awareness and interest in biomedical engineering, unless it is complemented with appropriate anatomy and physiology 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 an overall background to pull together many of the topics to which they have been exposed during the previous years' BME experiments.

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.

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