Development of Modules and Labs for "Biomedical Engineering Across the Curriculum"

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Abstract

With the present need for medical devices that combine mechanical systems and materials with sophisticated electronic components, there is a concurrent need for engineers who have a combination of both strong traditional and specialized engineering skills. There is also a growing need for all engineers to have some familiarity with the human/biological aspects of engineering. To produce such engineers, an educational program must provide a comprehensive interdisciplinary engineering background combined with a broad-based education in biomedical engineering (BME). Our goal, therefore, was to develop the courses and laboratories needed to establish a new concentration in Biomedical Engineering built upon the broad core of a General Engineering (BSE) degree. In addition, *every* student enrolled in one of our concentrations should gain exposure to BME principles and have experience in a BME laboratory.

Freshman and sophomore students are currently enrolled in the BME program. In addition to specialized BME courses, educational materials are being developed for inclusion in existing electrical and mechanical courses with the goal of familiarizing students with these principles, introducing "biomedical engineering across the curriculum." Modules of biomedically - related tutorials and problems have been prepared and are being implemented in our general engineering courses in electric circuits, statics, dynamics, and thermodynamics. Additional BME modules are being developed for five other core-engineering courses and several upper-level courses. These modules will be made publicly available to other programs through our web site. In addition, a BME laboratory experiment using the *Biopac* ™ System for physiological measurements has been added to the Instrumentation and Measurements Laboratory course taken by every engineering student regardless of concentration.

Introduction

Today's medical devices, particularly those utilized in the areas of prosthetics and artificial organs, are a combination of mechanical systems and materials with sophisticated electronic components. To continue to enhance these devices there is a need for engineers who have a combination of strong interdisciplinary traditional and specialized biomedical engineering skills. Towards this end, in the Spring of 2001 LeTourneau University began to develop the courses and laboratories necessary to establish a new concentration in biomedical engineering built upon our broad core curriculum. This concentration is designed to prepare future engineers for professional biomedical positions in industry and for graduate study in BME, the biomedical sciences, and/or medical school. Freshman and sophomore students are currently enrolled in the program.

For over twenty years the Engineering program at LeTourneau has offered an ABET-accredited General Engineering (BSE) degree. Concentrations are available in electrical, mechanical, and, recently, welding and computer engineering. In the first two years, all students take several core courses in electrical and mechanical engineering, as well as a laboratory course in welding principles and manufacturing operations. Biomedical engineering is being developed as a fifth concentration, built upon the common core.

Part of our approach to the BME concentration includes a special integration of curriculum. The concept of curricular integration has been occurring at all levels of education, from primary grades through graduate school. In the spirit of past academic emphases on "writing across the curriculum," "ethics across the curriculum," "computers across the curriculum," and "design across the curriculum," the approach we have taken is that of introducing "biomedical engineering across the curriculum." Specialized materials (modules) are being developed for inclusion in most of our existing traditional courses as a method of familiarizing all students with BME principles. In addition, a biomedical experiment has been added to a sophomore level instrumentation laboratory which is required of all students.

Our major goals in preparing the BME program are these:

1. A student majoring in biomedical engineering will have a strong foundation in traditional engineering subjects (particularly circuits, statics, dynamics, and thermodynamics), coupled with a specialized background in biomedical applications (bioinstrumentation, biosignal processing, biomechanics, biocontrols). Students will realize the relationship between core topics and BME applications as well as the connection between biomedical engineering and other engineering disciplines.
2. A student majoring in *any* engineering discipline should have some familiarity with the human/biological aspects of engineering. Every engineering student should have exposure to BME principles and some experience in a BME laboratory setting.

Part of the goal of exposing every student to biomedical concepts is to cause them to think seriously about safety and also about the place of the human body in their designs.
Safety of the user is a key constraint in all design. By understanding more about the heart, students have a greater appreciation for electrical safety and an awareness of the risk of fibrillation if currents pass across the heart. Human considerations in design would also include ergonomics (making sure that the equipment is designed to fit the person rather than the person forced to fit to the equipment) and human factors (understanding the types of actions humans are capable of doing and the types of displays humans are capable of reading).

Modules

Because of the structure of our curriculum, we chose not to develop separate biofluids, biothermodynamics, and bio-heat transfer courses; instead, we built on our common core courses. In this way, we were able to stay within the basic core curriculum which is required of all engineering students while providing biomedical exposure through various modules.

In 1994, a paper was presented for ASEE giving a survey of bioengineering problems for standard chemical engineering classes[1]. This article outlined a study in which individual problems were incorporated into chemical engineering courses. In the "biomedical engineering across the curriculum" project, we have established stand-alone modules with homework problems across a broad range of electrical and mechanical courses. For every core course, a module is being made available for insertion into the curriculum. The module is a short "packaged lesson," used as a bridge between the curriculum topic and a biomedical subject. The module can either be developed into a lecture, inserted as part of a lecture, or given as an assignment. The first modules include BME applications for circuits, statics, dynamics, and thermodynamics.

The circuits module provides an introduction to various batteries, including special considerations for pacemaker batteries. Students receive an introduction to battery structure, energy density, and battery ratings. They examine the advantages of lithium systems as having the highest energy density of the various cells studied and discuss the unique features of pacemaker batteries[2].

The theme of the module used for statics is the distribution of muscle forces for a joint with a given joint moment. Students are given two systems, one determinate and the other indeterminate. They are challenged to think of methods in which to distribute the individual muscle forces. Their results are then be used to estimate joint contact forces. In a similar manner, the module for dynamics concentrates on muscle forces across a joint with motion. The same type of module developed for statics is used, with various kinematic conditions.

The thermodynamics module explores basic concepts of bioenergetics [the theory of energy transfer in living systems][3]. Typical questions posed to the students include:

- Is heat a useful form of energy for performing biological work?
- Are cellular processes isothermal?
- Are living organisms reversible systems?
- What is the mechanism by which energy is transferred to living cells?

Additional core courses enhanced by biomedical modules include:

- Introduction to Design (measurements of human motion)
- Materials Engineering (considerations in biomaterial selection)
- Digital Electronics (equipment design for single heart cell studies)
- Mechatronics (motion control for prosthetics)
- Project Management (steps to FDA approval of medical devices)

Every engineering graduate will have at least nine opportunities for exposure to BME principles through the course modules. Upper-level concentration courses (electives) which fit well with modules include fluid mechanics (blood flow contrasted with water flow), electronics (biopotential amplifier design), heat transfer (mechanisms of heat loss from the body), and digital signal processing (signal averaging for evoked potentials).
Modules are tested and continually revised. In addition, we are considering the development of optional BME modules for our physics, chemistry, and calculus courses.

All of the modules prepared will be made available to any interested party through our program website.

Laboratory Experimentation

All engineering students in our programs are required to take an engineering course titled *Instrumentation and Measurements Lab*, which meets once a week throughout the semester at the sophomore level. Most experiments in this course involve familiarization with meters and oscilloscopes and measurements of electrical quantities. One session of this laboratoryis now dedicated to a biomedical experiment for all students.

For this experiment (and others involving signal processing), LeTourneau University purchased a *Biopac™* Student Laboratory System[4]. This system includes an interface box (MP300) and the necessary software and transducers to run numerous physiological experiments, including EMG, EEG, blood pressure, and pulmonary function. *Biopac™* is designed to eliminate complex setup tasks and to focus on the acquired signals.

The ECG (electrocardiogram, the waveform of the electrical activity of the heart) was chosen as a starting biomedical study because it is very easily recorded with three electrodes. The waveform is nearly periodic and has a readily identifiable shape (P,QRS,T). Waveforms corresponding to heart damage and basic rhythm problems are also recognizable. Information that students learn about signals can be readily applied to that particular signal.

The experiment was performed for the first time in the fall of 2001 for all sections of the lab. Nearly every student involved was an electrical or mechanical engineering major.
Detailed instructions provided the students with the knowledge necessary to carry out the experiment on their own. In the experiment, students were briefed on the ECG and its recording, one volunteer was connected to the electrodes, and a 30-second segment of the ECG was collected. Following the data acquisition, students were asked to observe the effect of filtering and differentiating the waveform and to determine the heart rate and basic wave intervals.

In surveying the students after the experiment, 62% indicated that they found the study interesting, and 43% found it useful (possibly applicable to something they will be doing in the future). The students reported that they learned the use and value of the ECG and the application of electronic instrumentation to medical problems. A few students indicated that they would be interested in additional work with the instrumentation. Comments from students included, “allow more student participation,” “more individual time with each specific instrument,” “do more things with it ... more experimentation,” and “show more than the heart rate.”

Conclusions

A major goal of the “biomedical engineering across the curriculum” project is to introduce every engineering student, regardless of major, to certain basic concepts regarding living systems and the human body. This objective is being accomplished through a common laboratory experiment in a required laboratory course and through modules inserted into traditional core courses. BME applications have been developed for circuits, statics, dynamics, and thermodynamics. Faculty teaching these courses have been interested in using the modules, and students are intrigued by the application of engineering science to the living body.

A number of changes will be made to the ECG experiment when it is performed again (Spring 2002):

1. In preparation for the experiment, detailed background information will be given to each student a week before it is done.
2. More than one student will be involved from several smaller laboratory teams, since students do not enjoy watching one student being measured.
3. A laboratory instructor or laboratory assistant will be involved in every phase of the experiment.

Even though the experiment was fully safe, the students were reluctant to follow the instructions and carry out the experiment on their own. This was probably due to the fact that they were recording from a living person and the heart was involved.

Additional experiments and modules will be developed over the next year. It is anticipated that graduates who have completed courses containing these enhancements will have a greater awareness of the place of the living body in their designs. The presence of biomedical engineering at LeTourneau University should benefit every student in our programs.

References

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Acknowledgements
Partial support for this work was provided by the National Science Foundation's Course, Curriculum and Laboratory Improvement Program under grant DUE-0087898

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