2006-2148: INTEGRATION OF DIVERSE LABORATORY EXPERIENCES THROUGHOUT THE BIOMEDICAL ENGINEERING CURRICULUM

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Integration of Diverse Laboratory Experiences throughout the Biomedical Engineering Curriculum

Abstract

Laboratory instruction is crucial in bioengineering curricula to introduce biological and physiological measurements as well as to foster an understanding of the complex nature of biological systems. Traditionally, stand-alone bioengineering laboratory courses provided students an opportunity to learn the function and operation of instrumentation as well as to analyze data by applying theories learned in lecture courses. More recently, studio environments have brought the lecture and laboratory together in a single course, emphasizing the relationship between theory and reality. This paper describes the use of stand-alone laboratories, studio-like environments, and a hybrid type of homework assignment, called physical homework, to provide hands-on learning experiences that are integrated throughout the biomedical engineering curriculum.

Introduction

Bioengineering laboratory courses are as diverse as the programs that offer them. Traditionally, laboratory experiences occurred within stand-alone laboratory courses that supported material learned previously or concurrently in lecture-based courses. More recently, many institutions have integrated problem-based learning into these courses.[1] Another recent development in bioengineering is the use of studio learning which involves the integration of lecture and laboratory in the same course and promotes active learning.[2,3]

The Biomedical Engineering program at Western New England College uses a variety of methods to deliver hands-on opportunities, integrating these experiences throughout the curriculum. These methods include stand-alone laboratory courses as well as studio-like learning, where laboratories and lectures are integrated, and a hybrid type of homework assignment called physical homework. Physical homework is similar to traditional homework, but includes an experimental component that can be performed individually by each student outside of a designated laboratory period or class. Specifics of the application of these types of hands-on experiences are described in this paper.

Physical Homework

The term "physical homework" has been used previously to describe a laboratory portion of a freshman engineering course that complements lectures on mechanics with real-life examples of these principles.[4] Our definition of physical homework is an assignment that is similar to traditional homework, but includes an experimental component that can be performed individually by each student outside of a designated laboratory period or class. In general, the data analyzed in the physical homework can be directly compared to that predicted using theory. Physical homework is especially useful in relating abstract mathematical concepts to real-world examples. Ideally, physical homework utilizes inexpensive equipment that is easy to duplicate or equipment that is readily available in undergraduate laboratories that can be used with minimal supervision.

Students are assigned physical homework in a sophomore-level biomedical systems course. An outcome of this course is the ability to analyze first and second order systems in the time, frequency, and Laplace domains. While many students mastered the mathematical manipulation of signals and systems, it was not clear that there was a link between the mathematical representation of the signals and systems and an actual physical system. In an effort to demonstrate the connection between mathematical representation of systems and actual physical systems, physical homework having both theoretical and experimental components is assigned at least four times per semester. The following is an example of a typical physical homework assignment.

Biomedical Systems (BME 202-02)
Spring 2005

Physical Homework #1
Assigned: February 25, 2005
Due: March 11, 2005

The purpose of this laboratory is to understand the analysis of first and second order systems in the time domain using RC circuit analysis. We have a number of different methods by which we can analyze these circuits: measuring voltage output from a physical system, deriving and solving for the output voltage using differential equations, and using MATLAB to solve the differential equations.

Physical systems:

Set up the circuit shown in Figure 1 using a breadboard, resistor, capacitor, and DC power supply. Since this circuit has one storage element, it is a first order system.

Push the output on/off button to allow the capacitor to charge. Push the output on/off button again to allow the capacitor to discharge. Measure the output voltage during charging and discharging using the oscilloscope.

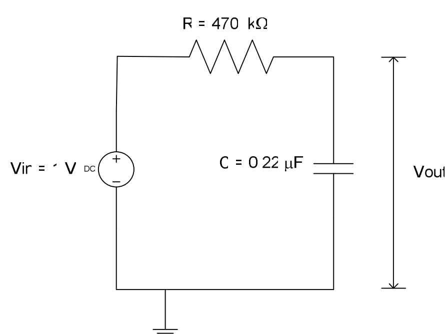

Figure 1: First order system with DC input

Now, we will use a sinusoidal voltage as the input to our circuit as shown in Figure 2. Set the function generator for an AC sinusoidal voltage with a peak-to-peak value of 1 V and a frequency of 10 Hz. Turn on the function generator and measure the output voltage, again using the oscilloscope to save your data.

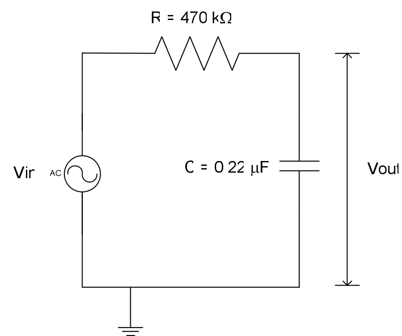

Figure 2: First order system with sinusoidal input

Now add a second resistor and capacitor to get the circuit shown in Figure 3. Since there are two storage elements, this is a second order system. Turn on the function generator and measure the output voltage, again using the oscilloscope to save your data.

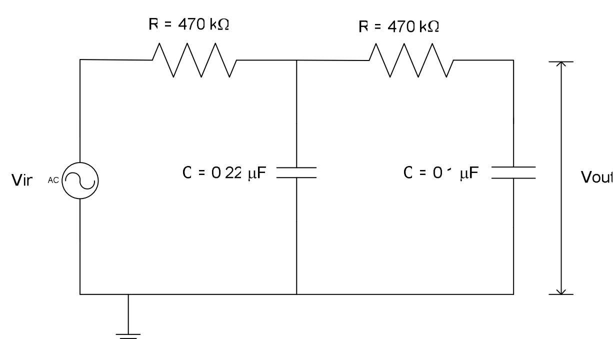

Figure 3: Second order system with sinusoidal input

Analysis:

Derive and solve the differential equations (by hand and with MATLAB) associated with these circuits. Compare your measured voltage output for these the solutions you obtain by solving the differential equations. In addition, for the first order system, determine the time constant during charging and discharging from your voltage measurements and compare these to the time constants predicted by your solutions to the differential equations.

These circuit models are easily built using breadboards and simple circuit elements. Instrumentation for measurements is available in the biomedical or electrical engineering labs that are open both evenings and weekends. In a similar vein, a mechanical model involving compliance and resistance of rubber tubing has also been used to demonstrate the physical significance of first order systems.[5] The mechanical model uses inexpensive tubing and pressure gauges that are supplied to each student for the assignment. These assignments serve to integrate concepts from differential equations, basic circuit analysis, engineering mechanics, and systems. There are plans to introduce physical homework into other required biomedical engineering classes in the future.

Studio-like Environments

Studio learning is effective in improving student learning during class time, especially with concepts that are normally difficult for students. Studio experiences are also important in fostering enthusiasm and independent thinking. Students in the studio environment are encouraged to consult with peers and faculty in the problem solving process. In other institutions, studio learning has been performed in dedicated classroom/laboratory space where a group of students is assigned a suite of relevant instrumentation. Space constraints as well as the economic challenges associated with the duplication of multiple instrumentation suites may make the true studio environment difficult to achieve on some campuses. We define studio-like environments as those integrated lecture/laboratory courses that foster active learning. The studio-like environment can be instituted without a dedicated studio classroom/laboratory space and duplication of expensive equipment. Class activities take place in technology-equipped classrooms or general laboratory spaces rather than in dedicated studio laboratory spaces, but still maintain their active learning nature.

Students in the biomedical engineering program are first exposed to the studio-like environment in a four-credit first semester freshman introduction to engineering course.[6] The major outcome for this course is an understanding of the design process and the use of tools to support the process. Each three-hour class is dynamic, with many activities occurring in this time frame, such as working on designs based on LEGO-DACTA RoboLab™ platform as well as learning the SolidWorks™ solid modeling package, Word, Excel, and engineering graphics and visualization. Each student works individually on classroom-supplied laptops on the computer-oriented activities. Small groups of 3 to 4 students work interactively on designs related to RoboLab™ platform. During each type of activity, students are mentored by a faculty member and an undergraduate assistant. Students are assessed on their understanding of the design process via written reports of their designs as well as quizzes, exams, and team meetings with instructors.

The studio-like environment continues in the freshman year in the second-semester engineering problem solving course where the outcome is the ability to solve engineering problems using computer tools (Excel, MathCAD, MATLAB). Again, classes are taught in a dynamic manner in technology-equipped classrooms with faculty serving as mentors in the problem solving process. Each student is again assigned a laptop computer for individual use during these classes. Both of the freshman courses model studio classroom environments with the exception of the use of a dedicated studio facility.

To carry forward the studio-like environment experience, biomedical engineering students are again able to learn in this type of environment in their first biomedical engineering course in the first semester of their sophomore year. One outcome of the introduction to biomedical engineering course is the ability to collect biological data with an appreciation of the complexity and variability of these data and, thus, a number of different laboratory experiences, representing a broad introduction to the field of biomedical engineering, are performed. Due to availability of equipment, these experiences follow one of two models. In the first type of experience, multiple stations of instrumentation are available for each group of students. An example of this type of experience is a reaction time experiment that is performed in the bioinstrumentation laboratory by small groups of students supervised by the course instructor. Each group has access to a PowerLab physiological data acquisition system (ADInstruments, Inc., Colorado Springs, CO). The availability of multiple systems allows the course instructor to monitor all students in the class as they perform the experiment during a single class meeting. In the second type of experience, when only one piece of equipment is available for an experiment, a rotation through a series of experiments is required. For example, three groups of students rotate through a group of three experiments: measurement of EOG signals during fixation and reading, heart rate and oxygen saturation levels via pulse oximetry, and concentrations of dye in solutions via spectrophotometry. Each group completes one experiment during a single class period. Because each student group is involved with a different experimental apparatus, a faculty member or laboratory supervisor must be available to interact with each group of students. A disadvantage of the second model is that the background material for all labs must be covered prior to the beginning of the rotation, eliminating the concurrency of theory and practice that is a staple of traditional studio learning. In both of these models, students are introduced to the equipment and complete simple experiments that demonstrate the measurement of biological data and then are assessed on their ability to collect and analyze these data via a laboratory report.

This studio-like environment is also used to aid student learning in their junior level bioinstrumentation class. As will be described later, laboratory experiences related to instrumentation topics are a component of our stand-alone laboratory courses. Additional hands-on experiences in the instrumentation course, presented interactively to complement the theory, include construction of a simple radio, design and analysis of basic AC circuits, reverse engineering of an ECG monitor, data collection and analysis from a sphygmomanometer, design of an EEG amplifier circuit, and image acquisition and analysis from an ultrasound phantom. These experiences are performed by groups of students during class time in the bioinstrumentation laboratory, supervised by the course instructor. As with the freshman courses, these experiences more closely match the traditional studio environment, but take place in a nondedicated laboratory space.

Traditional Laboratory Courses

Three traditional one-credit laboratory courses are required in each semester of the junior year and the first semester in the senior year for all biomedical engineering students. These conventional laboratory courses serve to integrate concepts such as instrumentation design, fluid dynamics, design of experiments, and the interface between living and non-living systems. This traditional laboratory approach is best suited for completing complex experiments requiring specialized instrumentation and large blocks of time.

These traditional laboratory courses offer students the opportunity to become familiar with specialized equipment, obtain data from living systems, and design both instrumentation and experiments. This three-course traditional laboratory sequence allows students to progress from simple performance of experiments on standard equipment using prescribed protocols, to the design of instrumentation, and finally, to the design of experiments for investigating hypotheses about physiological systems, integrating knowledge from previous laboratory and lecture classes.

The first junior laboratory course runs concurrently with a bioinstrumentation course and the first semester of a two-semester course sequence in engineering physiology and provides students with laboratory experiences and discussions on biomedical ethics. The outcomes for this course include the ability to use modern engineering tools to make measurements on and analyze data from living systems. The laboratory experiences include the measurement of EMG signals from human biceps/triceps muscles using a multi-channel biomedical amplifier and the determination of the rheological properties of mammalian blood using a cone-and-plate viscometer. These laboratory experiences are directly related to topics covered in the concurrent bioinstrumentation and engineering physiology courses. Students are assessed on their abilities to measure and analyze data through individual laboratory reports and a laboratory practicum exam taken by each student at the end of the semester.

The second junior laboratory course runs concurrently with the second semester of engineering physiology, biomedical thermal systems, and biomaterials. As in the first semester junior course, an outcome for this course is an ability to use modern engineering tools to make measurements on and analyze data from living systems. The laboratory experiences supporting this outcome are the measurement of ECG signals from humans using a multi-channel biomedical amplifier as well as the measurement of testosterone levels in mammalian serum using an enzyme immunoassay. An additional outcome for this course is the ability to design biomedical circuits to meet specifications. This outcome is supported by two laboratory experiences. The first experience is the design of a Wheatstone bridge circuit to be used with a thermistor to measure temperature in a thermal dilution experiment. The circuit must meet specifications on current through the thermistor, output range, sensitivity, precision, and maximum nonlinearity. This circuit is subsequently used to measure water temperature in a mock circulatory system during a thermal dilution experiment. The second experience contributing to students' abilities to design biomedical circuits is an experiment in which students use operational amplifiers to design, build and validate one and two-stage amplifiers for biomedical signals. These laboratory experiences are related to topics covered in the concurrent engineering physiology and biomedical thermal systems courses and build on material learned in the bioinstrumentation course in the previous semester. Students are again assessed on their abilities to measure and analyze data and design biomedical circuits through individual laboratory reports and a laboratory practicum exam taken by each student at the end of the semester.

The senior laboratory course completes the sequence of three traditional laboratory courses offered in the curriculum. The desired outcome from this laboratory is the ability to design and perform a case-control physiological study. Students work independently on a hypothesis-driven study of physiological function, performed on human subjects. Each student is free to choose the topic of interest for the study, based on equipment availability. Students must choose the appropriate hypothesis tests, perform power analyses to determine the proper number of subjects for their chosen levels of significance and power, obtain Institutional Review Board approval for their studies, perform the studies, and analyze and report the data. To be successful, students must integrate knowledge from their previous probability and statistics course as well as from previous laboratory and lecture courses related to bioinstrumentation. Students are assessed on their ability to design and perform the case-control study through a laboratory report.

Assessment of Results

We have presented various ways in which to integrate hands-on experiences into the biomedical engineering curriculum. There are two overall objectives of these experiences: 1) the introduction to students of the proper calibration and use of instrumentation that they are likely to encounter in their careers and 2) the facilitation of learning of concepts taught primarily in a lecture format.

The first objective is assessed using the practicum exams given at the end of each of the junior-level traditional laboratory courses. These exams measure student ability to perform simple experiments on instrumentation used in that semester's laboratory course and to analyze the results of these experiments. The expected performance level is that 80% of students will receive a score of 70 or better on these exams. A performance of less than 80% will trigger a discussion and possible changes in the pedagogy associated with this learning outcome. Since implementing the practicum exam in the first-semester junior lab in Fall 2003, 100% of students have received a 70 or higher on this exam, with a score of 90.2 ± 6.7 (mean ± standard deviation, $n = 16$). The practicum exam was instituted in the second-semester junior lab in Spring 2005. In this semester, 50% of students received at 70 or higher on this exam, with a score of 68.3 ± 21.3 (mean ± standard deviation, $n = 4$). The results from the first-semester practicum exam suggest that the students are successfully meeting the objective of understanding the application of instrumentation used in that laboratory course. Due to the small number of data points available from the practicum exam from the second semester, we can not make any meaningful conclusions concerning student performance on this exam. The scores from the second-semester practicum exam will be tracked closely to determine if intervention is necessary.

The second objective of facilitating learning of difficult lecture concepts can be measured by comparing scores on similar exams by students who did and did not perform the hands-on experiences. An example of this assessment is a take-home exam in the sophomore-level biomedical systems class that measures student ability to analyze second-order systems in the frequency domain. This take-home exam requires students to theoretically analyze a second-order RC circuit in the frequency domain by determining the poles, zeros, and Bode plot for the system and then experimentally verify and discuss the results. In Spring 2003, prior to the implementation of the physical homework, the score on this exam was 72.5 ± 15 (mean ± standard deviation, $n = 6$) while in Spring 2004, when the physical homework was assigned, the score on this exam was 78.7 ± 9.6 (mean ± standard deviation, $n = 6$). Although this difference is not statistically significant, the results suggest that the physical homework may contribute to increased student learning.

Choice of Pedagogy

This paper presents a variety of methods by which hands-on experiences are integrated throughout the biomedical engineering curriculum. The choice of a particular pedagogy depends on a variety of factors including the desired learning outcome of the experiment, the degree of interaction desired between faculty and students during the experiment, and the availability of instrumentation required for the experiment. Institutions may tailor their laboratory experiences based on their resources. Experiments that require expensive, one-of-a-kind instrumentation are best performed in either traditional laboratories or as part of a studio-like experience where small student groups are using the equipment at a given time. Inexpensive equipment that is easily duplicated can be used in either the studio-like experience or for physical homework. Faculty and staff resources may also affect the choice of pedagogy. In our model of the studio-like environment, each group of students is supervised by faculty or laboratory personnel. In programs with large numbers of students, the studio-like environment may not be feasible due to excessive demands on faculty resources.

Conclusion

The various pedagogies presented here have allowed the Biomedical Engineering program at Western New England College to integrate hands-on experiences throughout its curriculum, better engaging students in learning and fostering student interest in the biomedical engineering field.

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