AC 2008-384: ADDING BIOMEDICAL CONTEXT TO A TRADITIONAL ENGINEERING COURSE IN A BIOMEDICAL ENGINEERING CURRICULUM

Hatice Ozturk, North Carolina State University

Hatice Orun Ozturk is a Teaching Associate Professor of Biomedical Engineering and Electrical and Computer Engineering at North Carolina State University. She is also coordinator of assessment in both departments.

Lianne Cartee, North Carolina State University

Lianne A. Cartee is a Teaching Associate Professor of Biomedical Engineering at North Carolina State University. She is also the director of undergraduate programs.

Adding Biomedical Context to a Traditional Engineering Course in a Biomedical Engineering Curriculum

Abstract

The interdisciplinary nature of Biomedical Engineering programs requires that biomedical engineering students learn many traditional engineering subjects. The inclusion of biomedical context is then necessary for a complete learning experience. For simplicity, many traditional engineering courses are directly incorporated into biomedical engineering curricula with little or no modification, but the curriculum as a whole must address biomedical applications of these traditional engineering topics. Linear Systems is one example of a traditional engineering course with roots in Electrical Engineering that is a required course in many biomedical engineering programs. We designed a BME curriculum that includes a Linear Systems course as a co-requisite with a Physiology for Biomedical Engineers course. Students analyze data collected in the laboratory portion of the physiology course as part of Linear Systems course assignments. We aligned the topics to explicitly incorporate two physiology experiments that facilitate a joint learning experience. In the first experiment, students collect EEG data in the physiology laboratory and analyze the frequency content of that data in Linear Systems. In the second experiment, they study speech production in the physiology laboratory and perform a speech segmentation exercise in Linear Systems. In this paper, the experiments, assignments and assessment of the joint exercises are described, and an efficient way of bringing relevancy to a course imported from another discipline is demonstrated.

Introduction

The Biomedical Engineering Program at XXXX University has three emphasis areas: Bioinstrumentation, Biomechanics and Biomaterials and Tissue Engineering. Before BME students start taking elective courses in their specializations, they take courses from the Civil Engineering, Mechanical Engineering, Materials Science and Engineering and Electrical and Computer Engineering departments as they complete their basic science courses and core biomedical engineering courses. The courses offered by the Biomedical Engineering department, in contrast to the traditional engineering courses, are interdisciplinary and focus on the interface of engineering and biology. It is not surprising to find that, in general, students find the courses offered by the BME department much more relevant to their disciplines. In this paper, the specifics of how a Linear Systems course taught by the BME Department, but directly imported from an Electrical and Computer Engineering department increases in relevancy, as measured by

BME student ranking, with the inclusion of physical homework [1]. Our definition of physical homework does not involve modeling and measuring of identical systems but involves analysis of experimental data collected by a team in the hands-on laboratory of the Physiology for Engineers course which is aligned with the Linear Systems course.

Background

It is not difficult to imagine how the "before" picture looked. Physiology for Engineers and Linear Systems for Biomedical Engineers were taught during the same semester. The first course was taught by a Biomedical Engineering professor, the second by an Electrical and Computer Engineering professor with a BME background. They taught their courses independently; they did not look into integration opportunities; and they contributed significantly to the perennial complaint of BME students everywhere: "how is this relevant?" Biomedical Engineering students at our university are quite vocal about their undergraduate education. About 80% of undergraduates have plans to attend graduate school or medical school. Below is a sampling of student comments from Linear Systems for Biomedical Engineers end of semester evaluations:

"[this course] was very tough to comprehend and had little to do with actual BME applications."

"Course was very abstract and frustrating; did not seem to fit into biomechanics."

"More examples or a more diverse group of examples would be beneficial. The textbook was not as clear as it could be."

"I still don't really understand why this course is a requirement in the major. I see how it can relate to BME but not how I will use it at all."

End of the semester evaluations from Physiology for Engineers gave us a warning about taking a comfortable position with courses developed and taught by Biomedical Engineering Faculty. It is possible to develop a course in a discipline with a spectrum of valuable skills but not meet the needs of the students. Comments from end-of-semester evaluations included:

"[labs] hardly ever relate to class"

"The lab had absolutely nothing to do with the class"

"Felt like there was a bit of a disconnect between lab and class"

While the students enjoyed the labs, they were not able to see the relationship of the laboratory exercises to Physiology or Biomedical Engineering although other factors such as novel experiments and inexperienced teaching assistants may have also contributed to the problem.

The authors of this paper, who are also the instructors for the two courses, saw a unique opportunity for collaboration as a result of their involvement with BME undergraduate education, Director of Undergraduate Programs and Coordinator of Assessment, respectively.

Alignment of Topics

Table 1 shows how the topics of the two courses are aligned in a given semester to make physical homework assignments possible. There are 26 class periods in a semester excluding the tests and the number of class periods spent on a given topic is shown proportionally in Table 1. The connecting arrows indicate the two physical homework opportunities. The syllabi were jointly planned in advance in order to implement the strategy of linking the topics from both courses. The contents of the physiology for engineers sequence have been reorganized to make the physical homework possible. A similar implementation was given in [2] in an effort to integrate diverse laboratory experiences throughout the biomedical engineering curriculum.

The contents of the Linear Systems course shows that the material covered typical of any Linear Systems course in an Electrical and Computer Engineering discipline. The role of the Linear Systems course in the BME curriculum as a core course which also prepares the bioinstrumentation majors for senior electives such as Digital Signal Processing, Medical Image Processing, Control Systems and Digital Control Systems presented us a unique challenge: To make the Linear Systems course more relevant to all biomedical engineering majors when there is insufficient time to add new material.

Table 1. Alignment of topics in Physiology for Engineers and Linear Systems for Biomedical Engineers

<table>
<tr><th></th><th>BME301 Physiology for Engineers</th><th>BME311 Linear Systems for Biomedical Engineers</th></tr>
<tr><td>1</td><td>Introduction to topics</td><td rowspan="4">Time domain properties of signals and systems
BME Application: Mechanical, fluid and electrical modeling of BME systems, Example: Cardiovascular system.</td></tr>
<tr><td>2</td><td rowspan="2">Protein channels and their role in physiology
Lab: Nernst Potentials</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td><td rowspan="3">Nerves, action potentials and neural stimulators
Lab: Hodgkin Huxley Model</td></tr>
<tr><td>5</td><td rowspan="4">Impulse response representation of discrete and continuous LTI systems
BME Application: Modeling Skeletal Muscle, Example: Convolution of action potential and muscle response.</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td><td rowspan="3">Central nervous system, reflexes, brain, EEGs, functional imaging, deep brain stimulation and man-machine interfaces
Lab: Brain Dissection and EEG</td></tr>
<tr><td>8</td></tr>
<tr><td>9</td><td rowspan="6">Frequency domain representations of signals (Fourier Series, Discrete Time Fourier Series, Fourier Transform, Discrete Time Fourier Transform)

Physical Homework: Performing an FFT on the EEG data using MATLAB.</td></tr>
<tr><td>10</td><td rowspan="3">Cardiac electrophysiology, pacemakers and defibrillators
Lab: Heart dissection, EKG and heart sounds</td></tr>
<tr><td>11</td></tr>
<tr><td>12</td></tr>
<tr><td>13</td><td rowspan="2">Speech Production
Lab: Speech Lab</td></tr>
<tr><td>14</td></tr>
<tr><td>15</td><td rowspan="2">Autonomic Nervous System and Addiction
Lab: Cardiovascular Effects of Exercise</td><td rowspan="5">Frequency response of continuous and discrete linear time invariant systems
Physical Homework: Speech segmentation and analysis using MATLAB.</td></tr>
<tr><td>16</td></tr>
<tr><td>17</td><td>Sensory and somatic systems
Lab: Somatosensory Lab</td></tr>
<tr><td>18</td><td rowspan="3">Hearing and Cochlear Implants
Lab: Lateralization and Cochlear Implant Speech Processors</td></tr>
<tr><td>19</td></tr>
<tr><td>20</td><td rowspan="3">Continuous system analysis using the Laplace Transform
BME Application: Muscle reflex control and stability analyisis.</td></tr>
<tr><td>21</td><td rowspan="3">Vision, lenses and retinal implants
Lab: Eye Dissection</td></tr>
<tr><td>22</td></tr>
<tr><td>23</td><td rowspan="2">Discrete system analysis using the Z transform</td></tr>
<tr><td>24</td><td>Equilibrium and vestibular implants</td></tr>
<tr><td>25</td><td>Taste
Lab: Multi-dimensional scaling of taste</td><td rowspan="2">Feedback Systems

BME Application: Pupil control system.</td></tr>
<tr><td>26</td><td>Smell</td></tr>
</table>

Physical Homework

In this section, we will present both the laboratory experiments in the physiology course and the parallel physical homework assigned in the linear systems course.

EEG Experiment in Human Physiology for Engineers

In this experiment, you will record an EEG from a student volunteer. The objectives of the laboratory assignment are:

1. Learn the proper technique for electrode application for EEG measurement
2. Record an EEG using an AD Instruments [3] bioamplifier with appropriate settings
3. Observe alpha and beta wave EEG activity
4. Observe the effects of electrical and biological noise on your recorded signal
5. Learn techniques for reducing electrical noise when measuring biological signals

Physical Homework in Linear Systems

The objective of this assignment is to provide BME students with the skill of displaying the frequency spectrum of a given biomedical signal and manipulating it using built-in MATLAB functions. Students use the EEG signal they recorded in their Physiology laboratory.

1. Using the MATLAB plot function, plot the time domain signal, magnitude of its Fourier Transform and phase of its Fourier Transform on the same page.
2. Repeat step 1 for a 512 point segment of your EEG signal. Choose the segment from a section where the periodicity of the alpha wave is best observed. Compare the results of Parts 1 and 2.
3. Apply a low-pass filter of your choice to the EEG signal with a cut-off frequency of 20 Hz and plot the time domain signal before and after filtering on the same page.
4. Repeat step 3 with an ideal low-pass filter (cut-off frequency 20Hz). Compare the results of Parts 3 and 4.

Speech Laboratory in Human Physiology for Engineers

In this experiment, you will record your voice and other noise makers and observe the time domain and frequency domain representations of the sounds. This laboratory exercise is based on concepts discussed by Rossing [4]. The objectives of the exercise are:

1. Identify the fundamental frequency and harmonics of a vowel
2. Observe how the length of the vocal tract or an artificial tract changes the fundamental and harmonics of a vowel
3. Identify the formants of a vowel and recognize that 2 or more formants are necessary to form a vowel

4. Observe how the shape of the vocal tract or an artificial tract changes the formant frequencies of a vowel
5. Observe the difference between voiced and unvoiced sounds
6. Use an electrolarynx to produce speech and learn the function of the electrolarynx

Physical Homework in Linear Systems

The idea for this homework came from the textbook "DSP First: A multimedia Approach"[5]. Students analyzed a sentence that they sampled and recorded in their Physiology laboratory.

1. Plot the waveform of the "Thieves Who" speech signal as five 100ms segments on the same graph.
2. Write your comments about the nature of the signal in each segment. Describe key difference between vowels and unvoiced sounds.
3. Identify one voiced and one unvoiced segment of your speech and take 256 point Fourier Transforms of these segments using MATLAB.
4. Graph the magnitude spectra of the two Fourier Transforms computed in part 3.
5. Comment on the nature of the magnitude spectra; compare your vowel "ē" from the Physiology laboratory with this one.
6. Repeat parts 3 and 4 with 64 point Fourier Transforms and compare the results.
7. Take the Fourier Transform of the whole speech signal and compare the magnitude spectrum with part 4.

Students worked in groups in the physiology laboratory, but worked individually on Linear Systems assignments. Courses were listed as co-requisites. With one exception in each course, all students were enrolled in both courses. The single student enrolled in linear systems who was not in the Physiology course was given a set of pre-collected data for each assignment. Students used their own data for the speech assignment and used a shared set of data collected from one volunteer in their group for the EEG homework.

Results

The addition of physical homework in the linear systems class increased the biomedical relevance of both the linear systems course and the physiology course. This was indirectly assessed through the end of course evaluations. Before the alignment of courses, 10 out of 32 students who responded in the open ended comments section of the course evaluations for Linear Systems complained that the course was not relevant to their emphasis areas. After the alignment, only 2 students out of 24 complained about relevancy. In the physiology course, there were no comments on the lack of connectivity between the class and the laboratory assignments after the alignment of courses even though the laboratory assignments and lectures were not changed in any major way.

A summary of student responses to select questions from the course evaluations are given in Table1 before and after connecting the courses. Responses were on a scale from 1 to 5 based on level of agreement with 5 being strongly agree.

Table 2. Summary of student responses to three questions from the course evaluation forms before and after the alignment

	Physiology (Before) Fall 2005 N=39	Physiology (After) Fall 2007 N=21	Linear Systems (Before) Fall 2005 N=38	Linear Systems (After) Fall 2007 N=24	BME Dept. Fall 2007 N=300
Q 1	3.24 ± 1.1	4.52 ± 0.51	4.45 ± 0.68	4.63 ± 0.65	4.20 ± 0.89
Q2	3.34 ± 0.97	4.62 ± 0.5	4.10 ± 0.96	4.29 ± 1.0	4.18 ± 0.92
Q3	2.7 ± 1.1	4.25 ± 0.51	NA	NA	4.15 ± 0.62

Q1: This course was intellectually challenging and stimulating
Q2: The course improved my knowledge of the subject
Q3: Laboratory sessions contributed to mastery of course concepts

The effectiveness of the addition of physical homework assignments in Linear Systems was also assessed through a student questionnaire. Students were asked to gauge the level of biomedical engineering content in four courses. 1. *Linear Systems (with the addition of physical homework).* While this course was offered by the BME department, it is a traditional Electrical and Computer Engineering course that was directly incorporated into the BME curriculum by only changing the applications from Electrical and Computer Engineering to Biomedical Engineering. 2. *Thermodynamics.* This is a traditional engineering course taught by the Mechanical Engineering and Material Science and Engineering departments. The course has no connection with BME. It is a service course that is taught to students in many engineering majors. 3. *Dynamics.* This is also a traditional engineering service course. It is taught by the Mechanical and Civil Engineering departments and has no connection with BME. 4. *Biomaterials*. Biomaterials is a true BME course developed for BME students.

As well as gauging the biomedical content, students also rated the relevance of the same 4 courses to BME. Relevance and content were rated on a scale of 1 to 5 with 1 being the least relevance or content and 5 the highest. Data from the student survey are shown in Table 3.

Table 3. Summary of student responses to four courses in the BME curriculum in terms of their relevance to BME and their BME content (N=42)

Course	Relevance to BME	BME Content
Linear Systems--modified traditional engineering course	3.8	3.2
Thermodynamics – traditional engineering course	2.4	2.2
Dynamics – traditional engineering course	3.0	2.6
Biomaterials--BME course	4.2	3.6

The relevance of Linear Systems to BME was rated greater than that of both of the traditional engineering service courses with only the BME course considered to have greater biomedical relevance. Similar results were obtained for biomedical content. It is important to note here that of the 42 students who filled the survey, 20 are completing the Biomaterials area of emphasis, 12 Biomechanics and 10 Bioinstrumentation. When we looked at the average scores of these groups separately, we observed that they were very similar which supported our finding that increasing relevance to BME changed Linear Systems from a prerequisite course for bioinstrumentation students that was required of students in all areas of emphasis to a true core course in the BME curriculum.

The direct association of Physiology and Linear Systems seemed to improve the performance of students in the Physiology course. Students were asked to calculate the formant frequencies for a given vocal tract and vocal fold characteristics or the reverse problem, to calculate the length of the vocal tract given the voice spectra. To answer correctly, required knowledge of how the vocal tract filters the output of the vocal folds. In the first offering of the course, before the course was linked with linear systems, students scored an average of 74% correct on the question (with standard deviation of 2.0 and N=36). After the courses were linked, students scored an average of 81% correct on the reverse problem (with standard deviation of 6.8 and N=46), even though the reverse problem should be a more difficult question conceptually. In the Linear Systems course, 72% of the 44 students answered the question "If an impulse train is applied to a muscle with a period less than the time constant of the muscle's impulse response, what happens to the muscle?" correctly by describing the state of tetanus. We don't have a number to compare this performance before connecting the courses since they were never asked physiological modeling questions.

Conclusions

The joint learning experience between Physiology for Engineers and Linear Systems did help students understand the relevance of the measurement of biological signals to physiology and the role of linear systems in biomedical engineering data. Other alignments of traditional engineering courses with BME courses may be possible. However, some level of control over the traditional course will probably be necessary in order to align syllabi and to guarantee that the majority, if not all, of students registered for the traditional course have an interest in BME.

In the future, we plan to continue the alignment of Linear Systems and Physiology courses within our department and plan to look for physical homework opportunities in other courses.

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