UNDERGRADUATE EDUCATION-RESEARCH WITH BIOMEDICAL ENGINEERING LABORATORIES

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Abstract

As part of a larger endeavor to build upon a multi-disciplinary undergraduate engineering program, we have established a biomedical engineering laboratory as part of a distinctive curriculum for a Biomedical Engineering (BME) concentration. This laboratory is equipped with modern experimental equipment solely devoted to undergraduate education and research. Complementing this laboratory are exercises and procedures to orient the students to experimental equipment and its appropriate use and purpose. While these typical laboratory exercises orient students to the equipment and its proper use, the extended purpose of the laboratory is to use its set of experimental equipment as "tools" for students to answer educational/research hypotheses. Toward this end, students are required to formulate a question and a hypothesis. They would then use the proper experimental equipment and methods to verify their hypothesis. This larger task serves several purposes. It requires the students to (1) observe typical biomedical engineering phenomena, (2) formulate a hypothesis as to why the phenomena occurs, (3) develop an experimental methodology, and (4) gather the required experimental data to verify their hypothesis. Each student's work is then arranged either in poster format or a conference proceeding, as if they were submitting their work to a conference. We believe that this experience educates all of our undergraduate engineering students in proper laboratory use, experimental design, and research methodologies.

Introduction

Undergraduate education in engineering has traditionally prepared students to excel at engineering analysis and design, with a much lesser focus has been placed on experimental methods, especially scientific experimental methods. This engineering education has traditionally been formulated by means of students taking courses in engineering science and design with supplemental laboratory experiences. These laboratory exercises, however, are usually a much smaller component of a course. While the traditional laboratory exercises are worthwhile, they rarely contain *all* of the elements that are necessary to formulate specialized experimental procedures that can provide the data needed to give insights into a independent scientific inquiry. That is, laboratory procedures are typically used only to show already established scientific events. Our attempt has been to establish a biomedical engineering laboratory which is used in a notably different manner than the methods that have been traditionally been used as well as recently developed in undergraduate engineering education. Toward this end, we have developed a biomedical engineering laboratory with a broad set of experimental equipment and research software. Students are then familiarized with the various equipment and software capabilities during the early portions of their coursework. From that point forward, all laboratory assignments are formulated in such a way as to stimulate the student toward *independent* laboratory investigations. Our overall purpose is to educate students in the process needed to perform *effective independent* laboratory investigations using the scientific method from developing a hypothesis to the analysis of the experimental data needed to address the hypothesis.

Laboratory Goals

When the curriculum was designed for LeTourneau University's BME concentration, the curriculum's foundation was a well equipped laboratory. This would then allow for the students, who are already being educated in engineering analysis and design, to be educated in the broader aspects of scientific experimental methods.

To develop such a laboratory, a broad range of experimental equipment was acquired. The equipment currently available in our laboratory is as follows:

- A 5-camera *Motion Analysis*™ with real-time simulation used for normal, patient and athletic human motion analysis.
- A *Bertec*™ six degree-of-freedom force plate used to measure the ground reaction forces of a person walking, running, or jumping.
- A Servo-Motor with adaptive programming capabilities used to simulate various mechanical stiffness and feedback environments in the use of one degree-of-freedom joint movements.
- A 12 channel *Noraxon*™ EMG system used for the collection of muscle electrical signals used in human movement.
- A linear transducer used to measure rectilinear motion in experiments such as cadaver parameter measurements.
- A six degree-of-freedom load cell used to measure individual forces exerted by limbs or other various apparatuses.
- A 32 channel Analog to Digital (A/D) system for use in gathering data for analysis.
- A *BioPac*™ Student Lab System used to measure a range of various biological signals including ECG, EEG, pulmonary function and blood pressure.

Given the broad range of equipment available, a complete set of software is needed to use and perform a variety of data collection and analysis. This software is used for undergraduate education and must be relatively easy to implement. The software must also be robust enough that with some additional training our students can use it for their senior design experience and undergraduate research. The software currently available in our laboratory is as follows:

- *OrthoTrac™* is a clinical validated software package that is used to analyze and display kinematic, kinetic, and EMG data measured with the *Motion Analysis™* system.
- *LabVIEW™* is a graphical programming development environment used for data acquisition, data analysis, and data presentation. It is used regularly with our A/D acquisition system.
- *Software for Interactive Musculoskeletal Modeling™* (SIMM) is used to develop models of a musculoskeletal system for the estimation of muscle/ligament forces and joint contact forces.
- *Autolev™* is an advanced symbolic manipulator for engineering and mathematical analysis. With this tool student who know Kane's dynamics can develop sophisticated dynamic models of various musculoskeletal systems.

Given the equipment and software made available in the laboratory, an ample variety of experiments for class projects and undergraduate research are possible. Students only need to formulate their experimental techniques based on the equipment and software available.

Laboratory Exercises

Three "cookbook" experiments

A series of approximately three generic laboratory assignments are performed to familiarize the student with the majority of available equipment and software. The main objective of these fashioned experiments is not primarily to verify a particular phenomenon, but to provide a broad exposure to the laboratory and all the tools within. These experiments are as follows:

- *Maximum height vertical jump*: This experiment involves a human subject to be tested in the laboratory to measure how high the subject can jump. Students have to estimate the height of the jump using only the force plate data and then verify this estimate with the motion analysis system. The use of SIMM is incorporated to visually represent the jump and also the activation of the various muscles that contribute toward the jump. This experiment incorporates the use of the *Motion Analysis* System, the force plate, EMG system and SIMM.

- *Biopac* – EMG: This experiment involves the use of a hand dynamometer and EMG recording to explore the role of skeletal muscle in the activity of mechanical tasks. In this experiment the student grips the hand dynamometer with dominant hand and tries to estimate the grip strength exerted (0-50 kg). The student then attempts to maintain the same force for several minutes, but fatigue will cause a gradual diminishing of force. The student is asked to estimate when force has decreased to 75% and 50% of maximum (clearly visible on the force recording). The EMG record is then correlated with the force record to understand what is happening in the muscle.

- *Interacting with various stiffness environments*: This experiment involves the use of the servo-motor, EMG and data collection system. In this experiment the subject is strapped to a chair and the arm is secured to an arm rest that is attached to the programmable servo-motor. The subject is then asked to perform a series of cyclical elbow flexion/extension movements. At first the subject is free to move without any resistance. In subsequent experiments the stiffness of the motor is increased in varying proportions to joint angle and the subject is asked to keep the same movement amplitude and frequency as was done with no resistance. Data is collected over many trials and the students are asked to evaluate muscle activation as the stiffness of the environment varied.

Two Independent Experiments

After students have completed the three introductory experiments *and* have *demonstrated* working knowledge of the equipment available to them in our biomedical engineering laboratory, the students are then assigned two major independent experimental investigations of their choosing under the input, guidance and approval of the professor. During this investigation, they are to execute the entire scientific process in experimental design and must document this process in a research notebook.

At a minimum, students are required to perform the following steps:

a) Observe a biomedical event/process that intrigues but is not understood.
b) Construct a testable hypothesis.
c) Construct an initial experimental protocol to isolate the event/process.
d) Run an abbreviated preliminary experiment.
e) Review preliminary experiment for accuracy and possible sources of error.
f) Analyze preliminary data.
g) Refine experimental protocol based on experience gained from preliminary experiment.
h) Perform a full experiment.
i) Analyze final experimental data.
j) Interpret results.
k) Document sources of experimental error and estimate how error impacts results.
l) Attempt to prove/disprove hypothesis.

Presenting Results in Written and Oral Form

Students must then develop a two-page proceeding much like that prepared for a professional conference. Students may also use this proceeding to create a 3'x4' poster of their work. At a minimum, the paper/poster must include the standard sections of Abstract, Introduction, Methods, Results, Conclusions, References, and Acknowledgements.

We believe the final written proceeding is a critical part of the scientific process. It educates students to experience the development, struggle, and rewards of publishing. It also helps them understand that effective documentation of their results in published form is a critical part of the scientific process. Scientific knowledge must be disseminated.

Students are then to prepare a 20-minute oral presentation with a ten minute question and answer portion. During this time they are to present not only their findings but also the entire process from speculation to final conclusions. After this process of "review" under Q&A from the professor, peer, and invited guests, it may be possible that if a serious deficiency is found in the experimental or data analysis process, that portions of the experiment and/or analysis may need to be redone and an Errata and a corrected paper/poster presented to the professor.

Educational Objectives

Clearly this detailed process for students to follow is primarily for educational purposes. These students are to learn to formulate, test, and present a research question, i.e. hypothesis. Our desired objectives are that the students learn, at a minimum, the following items:

a) Observation of biomedical events/processes.
b) Construction of an educated guess as to a casual effect.
c) Development of an experimental protocol that isolates item of interest.
d) Performing an experiment.
e) Collection of accurate data.
f) Interpretation of data.
g) Testing whether educated guess is justifiable.
h) Presentation of results.
i) Effectively dealing with peer review & Q&A – i.e. scientific criticism.
j) Gain an appreciation of the difficulty of being a good experimentalist.

Conclusion

As part of a larger endeavor to build upon a multi-disciplinary undergraduate engineering program, a BME laboratory for undergraduate education and research has been developed for a specialized concentration in BME at LeTourneau University. This new engineering concentration fits within the larger framework of a bachelors of science in engineering. The laboratory is a crucial part of the educational process of the students who are in the BME concentration. This laboratory has been equipped with a broad range of experimental equipment and research software so that students can develop strong experience in the complete scientific process in the design of experiments. This laboratory greatly assists in teaching students the experimental process. This process becomes extremely beneficial during their senior design experience and possible future graduate work. We believe that this detailed laboratory experience educates our undergraduate engineering students in proper laboratory use, experimental design, research methodologies and knowledge dissemination.

One last note, in the past the independent experiments that the students have develop has lead to larger independent undergraduate investigations which have then provided valuable areas of funded research for undergraduate students. This has been an unexpected, yet pleasant outcome.

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