AC 2010-598: A CONSUMER AND LABORATORY DEVICES APPROACH TO TEACHING PRINCIPLES AND APPLICATIONS OF BIOELECTRICITY

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A Consumer and Laboratory Devices Approach to Teaching Principles and Applications of Bioelectricity

Abstract

Courses in Bioelectricity, or similarly Bioelectric Phenomena, are taught within many undergraduate and/or graduate curricula in Bioengineering, Biomedical Engineering, and sometimes Electrical Engineering or Neurosciences. While most such offerings emphasize mainly the theoretical foundations of bioelectricity as applied to clinical devices and/or modeling of excitable cell function, we have supplemented this traditional approach in the course BME4504C at Florida Gulf Coast University through the incorporation of experiments and projects featuring consumer and laboratory devices. Featuring consumer devices available across the counter (e.g. percent body fat bioimpedance monitors or scales), or by prescription (e.g. transcutaneous electrical stimulation devices for pain suppression or muscle exercise), has helped students understand the widespread importance and application of bioelectric principles in device design beyond the hospital environment. Additionally, exposing students to selected laboratory instruments (e.g. electroporation systems) assists in emphasizing the applications of bioelectricity in fields such as biotechnology. The expense of incorporating consumer devices into a Bioelectricity course is low, and laboratory systems such as electroporation devices may already be in place in research labs. Student response to this approach to teaching Bioelectricity at the senior level of our undergraduate curriculum was very favorable in a first offering last year. This paper provides a summary of the course structure, content, projects and evaluation of assessment results from the first offering of this course with discussion also of additional project topics incorporated into the second offering.

Background

Courses in Bioelectricity or Bioelectric Phenomena can be taught as early as the freshman or sophomore years in some undergraduate curricula. More commonly, such courses are considered specialized subject matter at the junior or senior level, or are delivered as graduate classes. A survey of the now archived on-line Biomedical Engineering Curriculum Database[1] (now hosted by the Biomedical Engineering Society) found at least twenty-five programs which described a Bioelectricity/Bioelectric Phenomena course within their undergraduate or graduate offerings (or courses with similar content but with other names such as Electrophysiology, Applied Neurophysiology, Cardiac Physiology, Applied Bioelectricity, etc.). Given that most entries in this database were last updated in the time period 2004-2006, it is likely that the number of programs offering Bioelectricity courses is now considerably higher. While some course descriptions in the database had corresponding labs indicated, or described use of 'virtual' labs, most Bioelectricity courses tend to be offered more as theoretical courses, often with corresponding use of simulations to reinforce understanding of models of cell cable equations, propagating and non-propagating action potentials, electrical stimulation of excitable cells, intracellular and extracellular recordings of cell activity, etc. Bioelectricity courses are often employed to introduce or reinforce concepts which, in the organizational scheme of the VaNTH Biomedical Engineering Key Content Survey (Round One)[2], fall within learning domains such as:

- Physiology - Cell And Tissue
  - Tissues Of The Body
  - Membrane Dynamics
  - Communication, Integration And Homeostasis
- Biothermodynamics And Physical Chemistry
  - Kinetics - Zero And 1st-Order Kinetics
  - Electrochemical Potential, Nernst Potential, Fick's Law
- Heat And Mass Transfer
  - Steady State Diffusive Mass Transfer
  - Diffusion Coefficients
  - Biological Membrane Transport Mechanisms
  - Nernst Potential
  - Osmotic Effects
- Physiology - Neuromuscular System
  - Efferent Peripheral Nervous System - Somatic Motor Division
  - Skeletal Muscle
  - Cardiac Muscle
- Physiology - Cardiovascular System
  - Cardiac Muscle And The Heart
- General Engineering Skills And Concepts
  - Numerical Differentiation And Integration
  - Generalized Ohm's Law
- Engineering Mathematics – Modeling
  - Compartmental Analysis
  - Deterministic And Stochastic Models
  - Using Quantitative Models To Simulate Physiological Systems
  - Numerical Methods
- Biosignals And Systems Analysis
  - Linear Systems
  - Convolution Of Signals
  - Auto-Correlation And Cross-Correlation Of Signals
  - Modeling In The Time Domain
- Bioinstrumentation
  - DC And AC Circuit Analyses
  - Electrodes For Biological Measurements
  - Transducer Properties

Our course, BME4504C, is taught at the senior level of an undergraduate B.S. curriculum as a 3 credit hour class which meets twice a week. Extended contact time (4 hours a week rather than 3 hours) permits us to more easily incorporate time each week into in-class problem solving, as well as running simulations, or carrying out the projects and experiments unique to our offering .

Course Learning Outcomes and Content

Learning Outcomes

Learning outcomes for this course involve five main themes as follows. After completing this course, students will be able to: (1) demonstrate understanding of relationships in cell membrane biophysics which are pertinent to design and use of medical and laboratory devices and diagnostic instruments; (2) use software tools for simulation of excitation and propagation in cardiac and neural tissues; (3) explain how both intracellular and extracellular biopotentials arise and are recorded; (4) explain how electric fields and currents can be used to stimulate cells and to defibrillate the heart; and (5) record and analyze common biopotential signals arising from the heart, nerves, and muscles.

Books & Resources

By far the most popular textbook for courses in Bioelectricity is Plonsey and Barr's Bioelectricity: A Quantitative Approach (now in its 3rd edition)[3]. In our course we use Plonsey and Barr as the required text, and also refer to the free on-line text Malmivuo and Plonsey's Bioelectromagnetism[4]. Other texts in use in Bioelectricity courses listed in the online Biomedical Engineering Curriculum Database (see above) include J. Patrick Reilly's Applied Bioelectricity: From Electrical Stimulation to Electropathology[5], and neurophysiology texts such as Johnston and Wu's Foundations of Cellular Neurophysiology[6]. Courses which follow Plonsey and Barr's content have main topics consisting of:

- Vector Analysis
- Sources and Fields
- Bioelectric Potentials
- Channels
- Action Potentials
- Impulse Propagation
- Electrical Stimulation
- Extracellular Fields
- Cardiac Electrophysiology
- The Neuromuscular Junction
- Skeletal Muscle
- Functional Electrical Stimulation

Experiments and Projects

In our course we do make use of traditional simulation tools to introduce aspects of bioelectricity dealing with cable theory, and non-propagating and propagating action potentials[7,8], as well as standard experiments designed to increase understanding of the principles of clinical EKG recordings[9]. The novel aspect of our offering of Bioelectricity is then incorporation of experiments and projects which expose students to a wide range of applications of bioelectricity fundamentals in the design and use of a number of consumer and laboratory devices. The intent here is twofold, (i) to utilize a variety and devices and instruments to reinforce students' understanding of the fundamentals of specific aspects of bioelectricity though investigation or use of such devices, and also (ii), to let students see the wide range of devices both in and outside of the clinical environment which make use of bioelectricity principles.

In both our first offering of this course last year, and again this spring, each student carries out an individual project according to the following guidelines.

> "Projects in this course entail the following:
>
> - Each student identifies an individual project on a topic pertinent to Bioelectricity in conjunction with the instructor,
> - Each topic needs to go beyond what we will cover in the course otherwise,
> - Within the topic chosen, the student identifies a good peer-reviewed journal article (review or specific study) that the entire class will read,
> - Each student designs and carries out on their own an experiment, activity, or simulation effort pertinent to their topic, and
> - Writes up a summary and methodological protocol of their experiment, activity, or simulation efforts that the other students in the class will use to also carry out the same activity under the lead student's direction, and then
> - Submits to the instructor a finalized written summary with methodological protocol including sample results."

For each project, the course instructor works with each student to identify a consumer device, prescription device, laboratory device, technology or principle to be emphasized. In cases where a device needs to be purchased, these have been bought by the department and kept for future use in instruction or class demonstrations or experiments.

Topic areas and devices, technologies, and/or principles for spring 2009 projects are detailed in Table 1. Projects underway in spring 2010 are making use of some of the same devices or technologies again (with differing methodologies), as well as several new devices. These projects are detailed in Table 2.

Table 1. Spring 2009 Project Topics, Devices, and Relationships to Course Content

Topic Area	Device/Technology/Principle	Relation To Typical Class Content In Plonsey & Barr (P&B) Or Malmivuo & Plonsey (M&P)
Impedance Based Body-Composition Devices	Omron Fat Loss Monitor Model HBP-306C (Consumer Device)	Volume Conductors, Impedance Methods
Transcutaneous Electrical Nerve Stimulation (TENS)	BMR Neurotech Smart-Tens Device (Prescription Device)	Electrical Stimulation
Magnetic Stimulation Bench- Model	Principles Using Hand-Made Coils, Function Generator, Oscilloscope, Power Supply In Relation To Theoretical Model (Demo Using Common Lab Instruments)	Magnetic Stimulation Of Neural Tissue
Skin Conductance	iWorx GSR200 Galvanic Skin Response (Teaching Device)	Electrodermal Response
Electroporation	BTX Harvard Apparatus Electro Square Porator Model ECM830 (Research Equipment)	Not In Typical Content

Table 2. Spring 2010 Project Topics, Devices, and Relationships to Course Content

Topic Area	Device/Technology/Principle	Relation To Typical Class Content In Plonsey & Barr (P&B) Or Malmivuo & Plonsey (M&P)
Impedance Based Body-Composition Devices	Compare Tanita BF679W Duo Scale Plus Body Fat Monitor with Omron Fat Loss Monitor Model HBP-306C (Consumer Devices)	Volume Conductors, Impedance Methods
Fitness Heart Rate Monitor	QRS Detection for Hand-Contact Heart Rate Monitoring in Exercise Equipment (Consumer Device)	Source-Field Models, Electrocardiography
Electrode Positioning and Orientation Effects in EMGs	Motion Lab Systems Multi-Channel EMG System Model MA-300 (Research Equipment)	Source-Field Models, Electromyography
Electroporation and Electrodiffusion	BTX Harvard Apparatus Electro Square Porator Model ECM830 (Research Equipment)	Sources and Fields, Bioelectric Potentials
Sensory and Motor Responses to TENS	BMR Neurotech Smart-Tens Device (Prescription Device)	Electrical Stimulation

Assessment and Evaluation

Each student's final project write-up (especially in relation to design of experiments) and their final project presentations were assessed for accreditation purposes following the spring 2009 offering. All five students achieved at our program's metric level for 'highly competent' (85% or higher of available points on rubric-based assessment matrices) on both tasks. Anecdotally, one student comment on our anonymous program Senior Exit Survey also spoke to the value received from the projects in our Bioelectricity course. In response to the exit survey question, "what were the best one or two things about your overall undergraduate experience in Bioengineering?", this student replied…

"… working with devices in Bioelectricity …"

More formal and quantitative assessment and evaluation of the impact of the project format in BME4504C Bioelectricity is underway for the current spring 2010 offering.

Discussion and Conclusions

In conclusion, we have developed and continue to refine a project-based version of an undergraduate Bioelectricity course which combines the traditional approach emphasizing a quantitative and theoretical focus in electrophysiology with student creation of experiments and class demonstrations based upon a wide variety of consumer or prescription medical devices, laboratory research instruments, and bench top models. This approach should be easily adoptable and adaptable for instructors at other institutions.

Acknowledgements

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References

1. See: http://bmes.seas.wustl.edu/Whitaker/.
2. D.W. Gatchell and R.A. Linsenmeier. The VaNTH Biomedical Engineering Key Content Survey, Part Two. *Proceedings of the American Society for Engineering Education*, Honolulu, HI, June, 2007. Also, see listing at: http://www.vanth.org/curriculum/Key_content_survey.asp.
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4. J. Malmivuo and R. Plonsey. Bioelectromagnetism. Oxford University Press, New York, 1995. Available free online at: http://www.bem.fi/book/.
5. J. Patrick Reilly. Applied Bioelectricity: From Electrical Stimulation to Electropathology, Springer, 1998.
6. D. Johnston and S.M-S.Wu. Foundations of Cellular Neurophysiology, MIT Press, 1994
7. HHSim, a graphical Hodgkin-Huxley simulator can be found at: http://www.cs.cmu.edu/~dst/HHsim/.
8. Nerve Version 2, which simulates generation and propagation of HH action potentials, can be found at: http://nerve.bsd.uchicago.edu/nerve1.html.
9. We use a Human Physiology Teaching Kit from iWorx Systems, Inc. as a platform for teaching basics of cardiac and neuromuscular electrophysiology; see: http://www.iworx.com.