AC 2007-1425: DEMONSTRATING NEURAL FUNCTION THROUGH BOTH HANDS-ON AND COMPUTER-SIMULATED LABORATORY MODULES

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Demonstrating Neural Function through Both Hands-on and Computer Simulated Laboratory Modules

Abstract

The Department of Biomedical Engineering (BME) at Illinois Institute of Technology (IIT) focuses on three areas of study: Cell and Tissue Engineering, Neural Engineering and Medical Imaging. Within the Neural Engineering curriculum, students take a core class called “BME 445 Quantitative Neural Function”. The major objective of this class is to teach fundamental concepts of neural function with an emphasis on quantitative analysis. Originally, this class was created as a lecture only class based on a traditional neuroscience class. However, it has been shown that students learn more effectively when the concepts are demonstrated through either hands-on or computer simulated laboratory modules. In order to enhance the learning experience, several laboratory modules and computer simulations were incorporated into the BME 445 class. Students found the modules enjoyable and helpful to deepen their understanding of the material. Overall, it was beneficial to introduce these hands-on experimental modules into a traditional neural science class for the BME students.

Introduction

What is hands-on learning? An hands-on learning approach requires students to become active participants instead of passive learners who simply listen to lectures. The concept of “hands-on learning” is not new in engineering education. A previous study of engineering education showed that hands-on learning is an effective method for engineering classes.[1] In fact, over the past 10 years or so, many engineering schools and programs have started to adopt “hands-on learning” into their curricula. Whether using simple everyday household items or sophisticated equipment, professors are now trying to integrate hands-on learning into their classes. Laboratory activities are the traditional method of providing students hands-on experience. However, with advancements in technology, students can participate in a non-traditional form of hands-on education through use of computers. This methodology may include running computational simulations on personal computers as well as web-based learning programs.

The Department of Biomedical Engineering (BME) at Illinois Institute of Technology (IIT) focuses on three areas of study: Cell and Tissue Engineering, Neural Engineering and Medical Imaging. Within the Neural Engineering curriculum, students take a core class called “BME 445 Quantitative Neural Function”. This class was originally created as a lecture based class. The emphasis of this class is to teach the basic principles of neuroscience to biomedical engineers. Our students who take this class generally have only one year of biology with no prior exposure to neuroscience. Since our BME curriculum is new, there has been an emphasis on integrating more hands-on learning into our classrooms. With this in mind, BME 445 was re-organized to incorporate more hands-on learning techniques to demonstrate neural science principles. The major objective of this class is to teach the fundamental concepts of neural function with an emphasis on quantitative analysis and to illustrate these concepts through hands-on experiments.

Several laboratory and computer simulation modules will be discussed in this paper. A comparison of the effectiveness of laboratory modules will be made to a traditional neuroscience class.

Computer Simulation Modules

In order to demonstrate the membrane electrophysiology concepts, a professor can choose one of several software programs that simulate experiments. We used "Neurons in Action" by John W. Moore and Ann E Stuart[2]. The objective of this software program is to demonstrate the complexity of a single neuron function. The simulation is based on the Hodgkin and Huxley equations describing results of squid giant axon experiments. The simulations allow students to reproduce the results of real experiments. The program is Windows-based and is easy to use. Various panels control experimental settings and plot the results. A major advantage of this program is that students can perform a wide array of virtual experiments which in a real laboratory setting would be difficult to do. The technique is difficult and it is not realistic for undergraduates to learn and perform the experiments, yet through the computer simulation, they are able to uncover famous results.

There are a total of 17 modules ranging from membrane potential to cable theory. We used four modules as homework assignments to demonstrate membrane potential, patch resting potential, passive axon (resistance, diameter) and cable theory. For example, resting potential of a neuron was one topic presented in BME 445. Three lectures were given in the class on resting potential. In the lectures, the basic concepts of resting potential and a derivation of the Nernst equation were discussed. Then, as a homework assignment, the students used the "Patch Resting Potential Tutorial" to further explore the concept. This module demonstrates two basic concepts: 1) that the resting potential is determined by the internal and external concentrations of ions to which the membrane is permeable and 2) how it obeys the Nernst equation were demonstrated through this module. With the simulation, students can alter ion concentrations inside and outside the axon patch setup, change membrane permeabilities and plot membrane potentials. For this experiment, the students explored three different types of resting potential experiments.

Another concept that has worked well with the computer simulation is postsynaptic potentials. Students often have a difficult time grasping this concept. By using the simulation, students can generate action potentials, examine refractory period, synaptic transmission, thresholds and how they govern the firing of action potentials. Students utilized a virtual patch voltage clamp technique, a key tool in neural science, to explore these concepts.

A major benefit of this software is that students can visualize experimental events. Concepts such as what will happen if concentrations of ions change and changes in potential due to injection of current are hard to visualize in lecture format. The software allows students to see the potential responses while changing different parameters and, hence, gain greater insight into the neural behaviors.

Laboratory Modules

Several laboratory modules were also incorporated into BME 445. Two of the laboratory modules were anatomy laboratory exercises. First, they dissected and examined bovine brains in the 2^{nd} week of the semester and then later in the semester they examine bovine eyes. Students underwent basic safety training by the instructor on the handling of fresh samples. This training is in addition to the basic laboratory training they received in the previous semester. Because most students have been exposed to some level of dissection laboratory previously, in this class, we challenged the students further. Instead of providing students with a detailed protocol, the students had to devise their own protocol. As a guideline, they were instructed that they had to identify certain parts of anatomy, describe their functions and using the data, they had to discuss one of the five brain disorders discussed in the class. Students used the web and textbooks to research dissection techniques, including finding a short movie clip which they brought to the laboratory as a reference. After executing their protocols, the students wrote laboratory reports based on their findings. Many of them took images of their samples and supported their answers with their experimental data. The process required them to learn about the structures and functions prior to the laboratory whereas if they had followed provided instruction, they would not have done the research. Students felt that they learned more by researching the protocol. A similar laboratory module was used to study the visual system.

The anatomy modules were relatively simple and inexpensive labs. The department already had sets of dissecting tools and microscopes. The brains and eyes were purchased from a local slaughterhouse at a relatively inexpensive price. Overall, introducing simple laboratory exercises enhanced the learning of anatomy with minimal outlay.

We also included two electrophysiology laboratory modules in BME 445: Electroretinogram (ERG) on anesthetized rats and Electromyogram (EMG) on human subjects. We have 10 stations of basic electronic/data acquisition systems in our Instrumentation and Measurement laboratory. Using PowerLab data acquisition and its software, we were able to conduct both ERG and EMG laboratory modules.

Electromyogram Module

For EMG module, simple surface electrodes were used to investigate fatigue and muscle activity in normal subjects. Students were introduced to skeletal muscle physiology, somatic motor neurons, the motor unit and how a neuron is activated and how muscle fibers are innervated in response to the neuron's impulses in the lectures. The principles and technical aspects of EMG were discussed. Students received a protocol outlining background information on motor neurons and a procedure to connect EMG electrodes and acquire signals. All of the students in BME 445 have taken the Instrumentation and Measurements Laboratory (pre-requisite class) and were familiar with the PowerLab system. Before the laboratory, the students then had to design an experiment to address three objectives: 1) demonstrate isotonic and isometric contraction and compare the EMGs, 2) demonstrate the effects of fatigue and 3) demonstrate the effects of motion artifact. Students were asked to formulate a hypothesis and design and test it experimentally. They were asked to specify which muscle was used and they had to measure from at least two different muscle groups. Their laboratory report was in the style of a BME journal article.

Electroretinogram Module

This module was more challenging because the recordings were done on anesthetized rats. This required several PhD graduate students from the instructor's laboratory to assist the class. Similar to the EMG, the students were given background lectures on the visual system and adaptation mechanism in the eye prior to the laboratory. The students also attended sessions on ethical issues of using animals (and humans for the EMG laboratory) and how to handle animals with the instructor. The objectives of the module were to investigate the effect of dark adaptation and light adaptation by examining ERG waveforms. There were three specific questions the students were required to investigate and include in the results in their reports: 1) How does response amplitude depend on stimulus intensity? 2) How long does it take to re-obtain maximum sensitivity after exposure to adapting light and does this depend on the duration or the intensity of the adapting light? and 3) How does the stimulus-response function depend on the presence of either a steady low background illumination or a brighter background illumination? The students were asked to design experiments that would address these questions.

The ERG setup was designed and built by the instructor and her students (undergraduate students working in her laboratory). A simple light flash setup was used to stimulate the eye. A small faraday cage was built to reduce noise as well as to provide a dark environment for the recording. A gold wire electrode (active) and two subdermal platinum needle electrodes (reference and ground) were used to measure the ERG signals and the Powerlab unit was used to collect the signals. Either Matlab or Excel was used to analyze the signals. Since the department has 10 stations of Powerlab units, the rest of the set up was relatively inexpensive. The major expenses (excluding Powerlab units) were camera flash heads and sync adaptors, which were purchased from a local camera store.

Evaluation

This class has been offered only two semesters and currently there is no quantitative evaluation on the effectiveness of the class. However, two forms of evaluation have been done to assess initial reaction and success of the laboratory modules.

First, a short survey of student feedback was given for a qualitative assessment. We limited the questions only to the EMG and ERG laboratory modules to find out if the experimental modules are valuable learning tools to be included in following years. Students were asked to give their thoughts on the effectiveness of the modules in learning the concepts of muscle electrophysiology and retina electrophysiology. In general, students liked the laboratory modules that accompanied the lectures. They liked the idea of writing their own protocols. The EMG laboratory was not technically difficult but they had to devise two different muscle sets to demonstrate the objectives which they found to be challenging. The ERG laboratory was more challenging since most of the students had never worked with animals. Monitoring the condition of the animal and collecting data involved detailed planning and strict execution of the protocol. This was a new challenge for most of the students. Some students found this module frustrating since they had to repeat the experiment due to noisy traces measured from the anesthetized animal. They had never been exposed to this type of *in vivo* recording in other classes and this was a new and challenging experience. However, in the survey, they agreed that this opportunity was unique and helped them understand the concept of dark adaptation. Also, in an indirect way of gave them an understand of life in a research laboratory. Based on this qualitative survey, we will develop a quantitative survey to assess the effectiveness of the modules. Future evaluation will include the effectiveness of computer simulation modules as well as dissection laboratories.

Second, to measure the level of learning of the dark and light adaptations using ERG responses, a comparison was made to a traditional neuroscience class. The instructor also teaches a portion of a senior/first year graduate level neuroscience class called Computational Neuroscience: Vision at the University of Chicago. In this class, the visual system is used to understand the neural function. The instructor delivers eight lectures on retinal function, including dark and light adaptations and ERG responses. This is lecture only class. The lecture material on the ERG and dark adaptation are the same as delivered in BME 445. On the midterm examination, the instructor used the same question on dark adaptation. On average, the BME 445 students scored higher on this question. They demonstrated a better understanding of the concept and how the experiments were done to measure the dark adaptation time. Based on this limited comparison, it seems that the hands-on experiment on dark adaptation helped students to understand the underlying principles. Further comparison is needed to test the overall effectiveness of the ERG module; however, the initial result is encouraging.

Conclusion

Overall, students enjoyed the computer simulations and laboratory modules as supplements to the lectures. The laboratory modules were more appealing to them since they were given an opportunity to work with animals. Also, they liked the experimental modules since they could write their own protocols. Even though it required more preparation time, it provide them a good understanding of the material before the experiments. The experimental laboratory modules were effective in providing students with a hands-on learning environment. The setups required relatively inexpensive materials and can be modified to work with various data acquisition systems. Computer simulation was well received and was an excellent supplement to the lectures. The only problem that the students encountered was accessibility to the program through the department computer laboratory. More computers are now installed with the program to alleviate this problem. In a qualitative evaluation of the modules, the modules were effective. Students found the modules enjoyable and helpful with their understanding of the material. Overall, it was beneficial to introduce these hands-on experimental modules into a traditional neural science class for the BME students.

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