TEACHING HANDS-ON BIOMEDICAL INSTRUMENTATION

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INTRODUCTION

Hands-on laboratory experience is an essential component of an engineer's undergraduate training. In this paper the above hypothesis will be supported via personal experience and results of a survey of programs offering biomedical instrumentation courses. Specific strategies for providing hands-on training, developed and implemented in the biomedical instrumentation courses at Louisiana Tech University, will be described. The strategies described are not new and in most cases are not even orginal, but rather an extension of techniques I encountered as a undergraduate student and as a teaching assistant under John Webster during graduate school at the University of Wisconsin-Madison. I have attempted to take the best from these experiences and implement/improve them in my own courses at Louisiana Tech University. The examples described here are used in a sequence of two biomedical instrumentation courses. The first is taught during the spring of the junior year and covers analog instrumentation. The second is taught during the fall of the senior year and covers digital signal processing. A design project in the second course requires students to synthesize the concepts from both courses and use them to design and build a complete instrumentation system. John Webster's text, "Medical Instrumentation," is used for the first course and Willis Tompkin's text, "Biomedical Digital Signal Processing," is used for the second course [1,2].

NEED FOR HANDS-ON LABORATORY EXPERIENCE

"Engineers put things together to make things that haven't been around before." - Joe Bordogna, NSF. Assuming this description of what engineers do to be accurate, an engineers training should be structured to allow the prospective engineer time to do engineering in a practical, hands-on way. In this section, several issues relating to the need for increased quantity and quality in the undergraduate laboratory experience are discussed.

Pressures to reduce credit load

Biomedical engineering is, by definition, multidisciplinary. Typical biomedical engineering undergraduate curriculum includes course work in basic engineering science, biology, physiology in addition to traditional pre-engineering course work in calculus, physics and chemistry. The need for multidisciplinary training and the pressures to reduce the total number of credits can result in the omission of laboratory courses outside of the biomedical engineering department. In our curriculum, for example, the physics laboratories are not required; not because the faculty has deemed them unimportant, but rather due to pressures to reduce the credit load.

Intrinsic value

The intrinsic value of hands-on laboratory experience goes beyond simply performing set experiments. To paraphrase the dictionary, engineering is the science or art of designing and building things [3]. So how does one become an engineer? Certainly the analytical methods learned in calculus and the fundamental truths of physics provide a basis for designing things. But the art of designing and building things is best taught via experience. For example, the idea of "thinking" in the frequency domain is quite esoteric until one experiences it in real terms (i.e. building an ECG amplifier, acquiring the ECG pre- and post- filtering and using a software package to examine the frequency spectrum).

In addition, hands-on projects and laboratory experiences provide a fertile ground for students to acquire skills in logical thinking, problem solving and basic troubleshooting. These are skills that are more difficult to teach in a lecture setting. In the lab environment, students are more apt to interact and learn together in a cooperative rather then competitive way. This supports a continued call for increased training in teaming and interpersonal communication skills[4]. Finally, lab experiences tend to give students a real sense of accomplishment. The results of their work in the lab are more tangible than a written homework problem.

Living systems

ABET (Accreditation Board for Engineering and Technology) program evaluation criteria states "...bioengineering laboratories must include the unique problems associated with making measurements and interpreting data in living systems and should emphasize the importance of considering the interaction between living and non-living materials." So in addition to the previous arguments, ABET criteria explicitly stresses the importance of aquiring data from living systems in bioengineering laboratories.

Survey results

A survey distributed via e-mail was sent to approximately 30 schools either known or thought to teach one or more biomedical instrumentation classes. Seventeen replies were received (4 of the 17 had no undergraduate BME program). The survey included questions about the number and content of any instrumentation courses, the number of hours spent on human subject and animal experiments and software used. Figure 1 shows the results of the survey relative to the total, the majority of the courses included less then 20 hours of human subject experiments and only 4 (31%) included any animal experiments. The results suggest that many programs are not providing significant hands-on laboratory experience for biomedical engineering students.

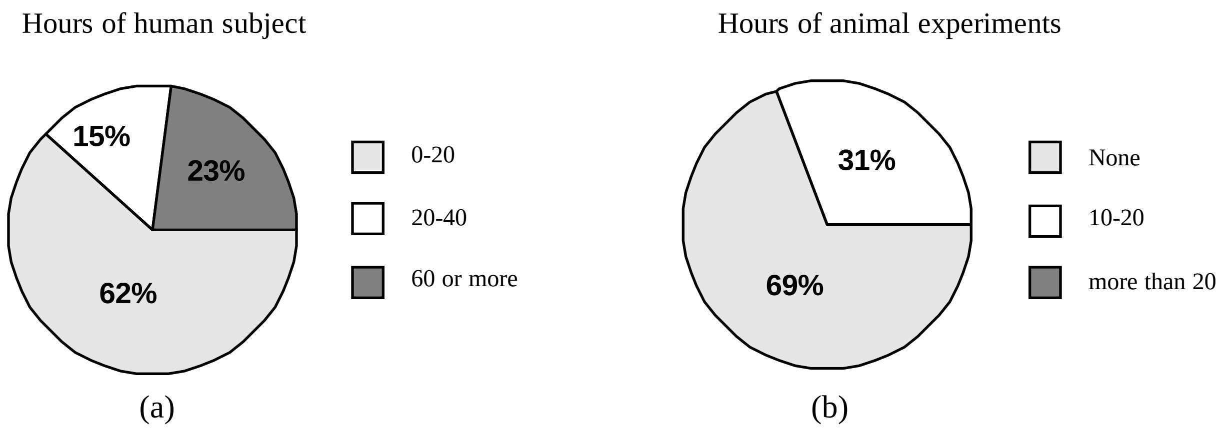

Figure 1 - (a) Most medical instrumentation course series contain 20 or fewer hours of hands-on experiments involving human subjects. (b) None contained more than 20 hours of hands on animal experimentation.

STRATEGIES FOR TEACHING HANDS-ON BIOMEDICAL INSTRUMENTATION

The strategies described below are only examples. They have been used successfully at Louisiana Tech and will hopefully be a valuable aid for others teaching medical instrumentation courses.

The labs

The labs should be designed not only to reinforce the lecture material, but also to teach students laboratory skills such as trouble-shooting problems, practical instrumentation methods, creativity, and ultimately system design (i.e. how to acquire physiological signals from the body to presenting the processed signal to the end user, and everything in between). This is accomplished within the framework of two 10-week courses at Louisiana Tech. Often engineering curricula does a rather poor job of teaching hands-on design. While this is currently being addressed at many universities via the introduction of freshman/sophomore level integrated design courses and through NSF funded programs such as EXCEL and SUCCEED coalitions, many curricula still do not introduce a hands-on design course until the junior/senior level. Thus, it is important that the first lab exercises have a high degree of structure. As the students gain basic skills, the labs progress in complexity and freedom of design culminating in an open-ended design project during the second course. The lectures and labs cover the general topics listed below in the order listed. Also listed are examples of topics covered in the associated laboratories. The beginning labs on safety and laboratory instruments are very structured. The subsequent labs become less structured leading to a group design project in which the students have total responsibility for design, construction and testing of a medical instrumentation system. While the laboratory experiments are performed in groups of 2 or 3 students, the use of bench exams (discussed in detail below) help insure each student is motivated to gain hands-on expertise in the use of the laboratory instruments (oscilloscope, power supply, function generator, data acquisition via LabVIEW). Student enthusiasm grows, along with their confidence as experimenters, culminating in the acquisition of their own ECG and EMG/ENG and the rat experiment.

Topics

safety
sensors and transducers
amplifiers and filters
biopotential amplifiers
origins of biopotentials
bioelectrodes
signal conversion
sampling and z-transform
finite impulse response filters
infinite impulse response filters
integer filters
signal averaging and adaptive filters
data reduction techniques
QRS detection
ECG analysis

Labs

Safety
Introduction to laboratory instruments
Basic amplifiers
Sensors and transducers
Biopotential amplifiers
ECG
EMG
ENG
Rat blood pressure and ECG
Group design project

Group design project

After completing the labs numbered 1-9 above, the students have a solid background in analog instrumentation and approximately 40 hours of hands-on laboratory experience. They have acquired physiological signals from both human and animal subjects, an understanding of basic safety considerations, built and tested a variety of analog filters and amplifiers and tested several sensors. At this point a group design project (Lab 10) is assigned. The basic project requirements and selected examples of actual projects are listed below. The students are given complete freedom in the choice of a project with the instructor reserving the right to veto any topics deemed inappropriate in terms of relevance to the course content. The basic filter in determining appropriateness is the following questions: (1) Can the topic be used to demonstrate the analog and digital concepts learned in the course? (2) Can the project be completed given the time and equipment limitations of the course? Approximately 10 weeks is allowed for project completion. Digital filtering techniques are covered in the lecture concurrently with the beginning phases of the group project.

Project requirements

design, build and analyze the instrumentation to acquire the physiological signal you choose
the acquisition of the signal in digital form and subsequent analysis and filtering
the application of the system/signal to a real problem
a 15-20 min. formal talk and demonstration of the project
a formal written report which follows the format required by IEEE Trans. on BME
the project must be relevant to the course content

Design project topics

Digital myoelectric controlled claw-type retrieving tool
Multifarious task controlled facial muscle-computer interface for hands-free operation (Face Mouse)
Heart rate monitor (via piezoelectric sensor)

Force variable switch
Determination of cardiac output via impedance techniques
Eye-driven mouse (based on EOG)
EMG-based back muscle overexertion warning device

The projects force the students to take the final and critical step in engineering education - to think for themselves. No longer is the answer given or even suggested. The design projects are not a follow-the-instructions experiment, but rather an actual engineering problem in many ways analogous to an entry level engineering assignment in industry. The students must work within the framework of a team to accomplish a common goal.

Bench exams

Invariably, students are teamed in groups of 2-4 students per group during lab periods due to limited equipment availability and limited instructor time. Typically one or two students in each group take the lead and end up doing the lab and the others strictly observe. However, the goal of the lab is to ensure that all students get ample time learning to operate the instruments, breadboarding circuits, etc. An effect and efficient way of ensuring all students are motivated to "get their hands dirty" is the use of bench exams. In other words, create the expectation that the students will be tested on their ability to perform the labs physically and not just turn in a written summary of the experimental results. At the beginning of the quarter, the students are given a detailed list of objectives and tasks which they may be asked to perform on the bench exam. This places the responsibility for learning on the individual. It is up to each person to be sure they acquire the skills necessary to perform the tasks on the list. To facilitate learning these objectives, open lab times are scheduled in addition to the regular lab periods. During the extra lab hours students are free to practice the tasks on an individual or group basis. It is made clear that the objective list is a minimum learning standard, but that if the objectives are mastered and fully understood the student should have no difficulty with on the bench exam.

The bench exams are typically 15-30 minutes in length. Two methods of implementation have been used. In the first, a question from the objective list is chosen at random and the student is asked to perform the task. Upon completion of the task another objective is chosen and so on until the time allowed expires. In the second, scheme the instructor writes a set of tasks designed to cover the most important concepts listed on the objective list. Both implementation schemes have been used at Louisiana Tech with good results. The students do not need to be informed about which scheme will be used, but only that they are responsible for full understanding of the stated objectives.

SUMMARY AND FUTURE WORK

"Education is a natural process spontaneously carried out by the human individual and is acquired not by listening to words but by experience in the environment" - Maria Montessori

As so eloquently stated by Maria Montessori, we learn by doing. The thoughts, ideas and examples described in this paper are intended to persuade you of the importance of learning by doing and give you come concrete techniques and ideas for teaching hands-on biomedical instrumentation. It is probable that many educators are already using these or similar techniques. Unfortunately there is not an organized method of distributing and sharing these ideas other than publishing at conferences or in the form of lab manuals or text books. In the future, the establishment of a electronic discussion group and associated web site dedicated to the exchange of ideas on teaching medical instrumentation could link instructors for the benefit of all students.

The following are selected quotes from recent student evaluations which I believe support the idea that teaching in a hands-on fashion is beneficial to the student and generates student enthusiasm in their work.

"I am taking 4 classes and this one takes up 50% of my time, but it is the only useful class of the 4."
"An exciting course."
"(The design projects were) great, a lot of fun although there were trials and tribulations the team work was good to have experienced."
"Good hands on experience with design"
"Good class, I really learned a lot"
"Very good course. Glad I had a chance to take it."
"Great experience, but frustrating sometimes"

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REFERENCES

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2 W. J. Tompkins, "Biomedical digital signal processing: C-language examples and laboratory experiments for the IBM PC," . Englewood Cliffs, NJ: Prentice Hall, 1993.

3 *Webster's New Collegiate Dictionary*. Springfield, MA: A Merrian-Webster, 1981.

4 Panel discussion, "Educating tommorrow's engineers," in *ASEE Prism*, 1995, pp. 11-15.

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Dr. Beebe is currently an Assistant Professor in the Department of Biomedical Engineering at Louisiana Tech University where he has taught a series of three medical instrumentation and signal processing courses. He is a contributing author to W. J. Tompkins (ed.), *Biomedical Digital Signal Processing* (Prentice Hall, Englewood Cliffs, 1993). His research interests include medical instrumentation and microelectromechanical systems.