Interdisciplinary Skills Development in the Biomedical Engineering Laboratory Course

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Abstract

A biomedical laboratory course has been an important part of the undergraduate curriculum in the Department of Biomedical Engineering, CWRU for several decades. It has undergone numerous modifications and adjustments, always following the contemporary trends and requirements of the science and engineering education, including current Engineering Criteria and Objectives by the Accreditation Board for Engineering and Technology (ABET). In its current form, it consists of two "tandem" courses, EBME 313 (fall) and EBME 314 (spring), in the junior year, and includes a number of educational components. These two courses are part of the Biomedical Engineering Core, and traditionally are among students' most favorite courses.

1. The course offers unique opportunities for the students to acquire hands-on experience in "real" research in a variety of biomedical engineering areas. Students perform experiments using the equipment and employing techniques that researchers use in their studies.
2. Students are trained to and required to write lab reports in form of full-length scientific paper, which gives them powerful skills in technical communication.
3. Students are required to deliver a computer-based presentation on one of their labs.
4. Students participate in grading the presentations of their peers, thus acquiring important skills in grasping material quickly, as well as in objective and fair judgment.
5. Several lectures/discussions on ethics in science and engineering in the beginning of the fall semester are appreciated by students as important and interesting experience which many of them encounter for the first time. A short essay concludes the ethics component.

Introduction

The technological and social development of humankind has resulted in rather dramatic changes in traditional spheres of science, art, economy, medicine, social life, moral, etc. Science and engineering have become collective enterprises as opposed to the individualistic approach of mere hundred years old society. In addition, and related to that, science and technology have entered everyday life and modified it radically. Thus travelers today can get very frustrated if they have to spent more than few hours going from New York to London across the ocean, yet they brag that it takes them just over an hour to commute between home and work... Young people have problems with handwriting, while they type at speeds that leave professional typists of the beginning of the 20th century badly jealous... When asked to divide 64 by 16 or to take log100, students start looking for a calculator… When one of the authors had to find the telephone number of my local telephone company, he immediately started searching the Internet, ignoring the telephone book with the number written on the cover in a 72-point bold-faced font.

The 2000-2001 Engineering Criteria[1] by the Accreditation Board for Engineering and Technology (ABET) include specific statements regarding the following aspects.

- The laboratory experience
  - conventional (I.C.3.f.):
    "Appropriate laboratory experience which serves to combine elements of theory and practice must be an integral component of every engineering program. Every student in the program must develop a competence to conduct experimental work such as that expected of engineers in the discipline represented by the program. It is also necessary that each student have "hands-on" laboratory experience, particularly at the upper levels of the program..."
  - bioengineering (II.D.3.e.):
    "The bioengineering program must provide the student with a meaningful laboratory experience, which implies an emphasis on practical engineering problems as well as on the basic functioning of biological systems. In particular, 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. An objective of the laboratory experience should be to educate engineers to be proficient in experimental work"
- The written skills (I.C.3.i.):
  "Competence in written communication in the English language is essential for the engineering graduate. Although specific course work requirements serve as a foundation for such competence, the development and enhancement of writing skills must be demonstrated through student work in engineering work and other courses. Oral communication skills in the English language must also be demonstrated within the curriculum by each engineering student"
- The ethical considerations (I.C.3.j.):
  "An understanding of the ethical, social, economic, and safety considerations in engineering practice is essential for a successful engineering career. Course work may be provided for this purpose, but as a minimum it should be the responsibility of the engineering faculty to infuse professional concepts into all engineering course work"

In the Biomedical Engineering Laboratory course we tried to integrate some of the important issues that are recognized by the educational community and in particular, are outlined in the ABET Criteria[1] and Objectives[2]. The CWRU BME Department established specific goals based on the ABET objectives in engineering education. In this course we intended to satisfy the following expanded ABET objectives:

a) to develop in students the ability to
   - measure physical phenomena relevant to medicine and biology using state of the art instrumentation
   - write effectively in a technical style
   - speak effectively to both technical and non-technical audiences
   - work effectively in a team setting
b) also, to make students upon graduation
   - be aware of real-life contemporary biomedical problems
   - be sensitive to biomedical ethical issues.

General Preparatory Lectures

In the fall semester, students are offered a set of lectures on basics of data analysis, statistical evaluations of data, and error analysis. The students are expected to prepare their laboratory reports in the style of a scientific journal publication. For many students this is a completely new experience. To assist in the development of paper writing skills, the students are provided with a lecture dedicated specifically to the topic and with the opportunity to perform a practice lab – the so-called "toy lab." Students really appreciate the discussion on writing a scientific paper. Many have little idea of what components must be included, and more importantly, why. Several key elements include an explanation of the importance spending time to produce clear figures and tables with relevant legends and descriptions, why a scientific paper starts with an abstract and/or an introduction, the role that concise and informative title may play, what is the difference between Methods and Results sections, and finally the importance of a solid conclusion.

Another element – fun and exciting – of the introductory part of the course is a "toy lab." Students are asked to conduct a simple experiment of their own design – freestyle – and write a small, yet complete, report on the results. The toy lab has proved to be a powerful educational tool in the lab course. First, students exercised their creativity, which is an essential component of engineering profession. Second, students get training in data analysis and report writing, which includes feedback from the coordinator who grades these reports. Third, students usually work in groups in conducting these toy experiments, acquiring important skills in collective problem solving and communicating with each other. The toy lab comprises 10% of each student's final grade, just enough to be taken seriously, but low enough not to punish students unnecessarily and allow a first evaluation of the student's weaknesses so they can be corrected before the completion of the first laboratory assignment.

Ethics

An important component of the laboratory course is the exposure of the students to ethics. Since biomedical engineering is interdisciplinary, including aspects of both engineering and the medical science, students are introduced to aspects of both engineering ethics and bioethics.

Early in the course a lecture is dedicated to engineering ethics. Student participation is critical to stimulate interest in the topics and a main role of the instructor is to act as a moderator. The first discussion topic consists of developing a definition of ethics. Points for discussion include the determination of what is morally right and legal versus ethical behavior. Some common practical ethics tests are provided for illustration and include the golden rule test, the front page test and the good night's sleep test.[3] The students come to realize that to act ethically means to do less that is allowed and more than is expected. The second discussion topic covered is the ethical obligations of an engineer. Students are introduced to the "Obligation of an Engineer" from The Order of the Engineer organization and to the Code of Ethics for Engineers of the National Society of Professional Engineers [4,5]. Each of the NPSE six fundamental canons are presented and discussed.

1. Hold paramount the safety, health and welfare of the public
2. Perform services only in areas of their competence
3. Issure public statements only in an objective and truthful manner
4. Act for each employer or client as faithful agents of trustees
5. Avoid deceptive acts
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession

Exposure of the students to the NPSE Code of Ethics is important, since many states include the basic principles in their professional engineering licensing legislation. For example, the Ohio Revised Code embodies the principles of the NSPE code under its six sections of responsibility to the public, public statements and certifications, conflict of interest, solicitation of employment, improper conduct, and other jurisdiction[6]. The idea that professional engineering practice is a privilege which will be revoked upon violation of ethical principles is stressed to the students.

The last exercise is a short case that is presented and discussed. A recent case used in the course dealt with an engineering manager asking a quality engineer to sign-off on the shipment of a part which had its packaging dented but was otherwise functional. The ethics issues involved are discussed, including values conflict between maximizing the economic performance versus social performance. “What would you do?” is a major topic of discussion along with determining if there are other options. Students are introduced to the idea that a good way to solve ethical dilemmas is to develop systems, which prevent ethical conflict from occurring where possible.

A complementary lecture is dedicated to bioethics. The area of bioethics is quite broad and the range opinions of various bioethicists can be quite broad. In the limited time available, the goals are to introduce the students to selected moral theories and principles and to available resources in bioethics. Another important goal is to make students aware of their own moral positions. This is important, since some of the laboratories open to the students use animal models. In making bioethics decisions students are introduced to the use of moral rules. On one extreme is particularism, which is the rejection of moral rules and principles in decision-making. It is intuition based and often includes the use of competent judges. Students tackle discussions regarding who is deemed competent, how is bias prevented, and how can decisions be generalized? On the other end of the spectrum is principlism often broken into deontology with its strict adherence to moral rules regardless of the outcome and into consequentialism with a utilitarian point of view. Regarding moral principles students are introduced to the four groupings presented by Beauchamp and Childress of nonmaleficence, beneficence, respect for autonomy, and justice. [7]

Discussion regarding moral principles are centered on the use of human subjects in experimentation. Students are provided references to the Nuremberg Code, The Declaration of Helsinki, and the Belmont Report [8-10]. Three key documents which form the basis of current bioethical opinion on the use of human subjects. The Belmont Report refers to the ethical principles of respect for persons, beneficence, and justice. Applications of the report involve issues of informed consent, risk and benefit assessment, and selection of subjects.

A case study is also used in this section of the course. A recent topic covered was "Can a Healthy Subject Volunteer to Be Injured in Research?" taken from *The Hasting Center Report*.[11] Again the role of the instructor during the case evaluation is to facilitate discussion and to help the students relate their moral position using earlier presented moral principles.

As part of the evaluation of the development of their ethics knowledge, the students are assigned an ethics essay to complete within a four week time frame. The assignment is designed to encourage the students to pursue in depth research in current ethics topics that are of interest to them. The essays, which are typically under a 1000 words, have covered a range of topics, such as oocyte donation, human cloning, genetic testing, and academic honesty. Some students have extended the assignment to evolving their essays to submissions for national ethics essay contests.

The laboratories

The strength of the course really lies in the variety and depth of the laboratories offered. Unlike previous experience students may have gained in introductory science courses, the laboratories which comprise this course sequence stem directly from the individual instructors’ research interests. Because the Department of Biomedical Engineering is jointly located in the Case School of Engineering and the Case School of Medicine, a large pool of instructors are available. In addition, adjunct faculty from the surrounding medical institutions are also frequent participants in the instructional processes, allowing students access to world-class laboratories at the Cleveland Clinic Foundation, the Cleveland campus of the Veterans Administration Hospital, University Hospitals of Cleveland, and MetroHealth Medical Center.

Students have to choose three (fall) or four (spring) labs in the beginning of the semester. Normally, about a dozen labs are offered each semester, so that students have plenty of options.

Students are encouraged to base their choices to increase depth in their biomedical concentration field and to use the opportunity broaden their knowledge in less familiar fields. Many students make their choices satisfy both. The wide choice options also help students to perform the lab experiments at most suitable times. To help students in choosing proper labs, lab titles, instructors, locations, and short descriptions are published on the web page of the course[7].

Laboratories available for students cover a variety of topics form fundamental scientific research to engineering design. For example, labs offered in the fall 2001 semester were: measurement of T-wave alternant, fluorescence imaging of intracellular calcium in retinal cells, imaging of cardiac reentry using voltage-sensitive fluorescent dies, measurement of cerebral blood flow using PET, estimation of heart valve compliance, quantitative properties of neuromuscular junction, determination of DNA sizes using gel electrophoresis and restriction enzymes, biomechanics of human posture and balance, using bioMEMS chips, and imaging using Optical Coherence Tomography (OCT).

The approach of letting students choose the labs among a variety offered has several advantages, including the following.

- Students have chances to satisfy their curiosity in engineering fields that are different from their major specialization. Thus students who follow a biomechanics track sequence can get experience in electrocardiogram recordings and analysis or several imaging techniques;
- Students can deepen their knowledge in their areas of concentration by performing experiments in the real life research environment.
- By choosing labs to conduct at convenient times, students maximize their performance and educational gain from the course.

Lab reports

As mentioned previously for each lab performed students must write a report in the form of a scientific paper. Such exercises train them for their future career, in which importance of technical communication skills can hardly be overestimated. The reports are graded by the instructors of the respective labs, with detailed comments provided. These comments emphasize both mistakes made by students and strong points in the reports. Since students take different labs, a special grading algorithm has been developed to diminish impact of subjective grading. To illustrate the problem, let us consider two labs from the fall semester of 2000. The average score in the lab of the toughest grader was 71.6±0.8% (mean±S.E.M.), while the easiest grader finished with 100.4±0.1% (some bonuses including). Therefore, an 85% score in the tough lab indicates actually excellent performance, while the same score in the easy lab can be considered as near a failure. After the adjustments for the subjectivity, the contribution of each lab into the final score did not show a correlation with "toughness" of the lab. This technique is also used to show students how to analyze data.

Computer-based oral presentation

At the end of the semester, students face another task: computer-based oral presentation. They have to choose one of the labs that they had taken during the semester – excluding, of course, the toy lab! – and prepare a short and complete presentation. Typically, students are broken into groups of five, and the session lasts for an hour. We try to organize the sessions so that students in the audience would not have taken the lab that is presented. The purpose of this is to imitate as close as possible the real life conditions, when a professional engineer is to deliver a technically loaded presentation to people with various backgrounds, often quite different from the speaker's. Students are required to participate in the evaluation of each other's presentations.

The presentation component of the course is very important, and usually students do very good job preparing for it. Below are some critical skills that are developed due to this component.

- Students get experience in speaking in front of an audience, which in this case consists of four or five of their peers, the coordinator, and the TA. It is a conventional understanding that undergraduate students may have lack of such experience; therefore, the opportunity to present their own results two times a year is exceptionally valuable;
- Students acquire crucial skills in compressing large amount of data and information into a short, 7-8 min talk;
- Students have to answer questions during 2 min question period at the end of the talk. This is one of the hardest skills to develop for a young and relatively inexperienced speaker. The speaker must understand the essential of the question within seconds, generate a proper answer, and formulate and deliver the answer in the clearest way. How often do we sit in the seminar room and watch in pain a speaker's attempts to understand a question that is absolutely transparent to us, or to explain the simplest?
- By participating in the grading process, students learn from the mistakes or advantages of their peers. Also, they obtain skills in being objective and fair – not an easy task. In many cases students tend to grade too high, and in a couple of cases a "slaughter" grading strategy was encountered, which mandated the use of the coordinator's "anti-subjective" adjustments.

Web-assisted course

Due to a complex structure and amount of information necessary for organization and conduct of the course, we maintain an extensive web site of the course[12]. The site provides students with all the necessary information, reminds them about deadlines and particular events, and keeps them updated about the performance in the labs. Any changes, updates and reminders are posted on the site promptly, and are sent to students via e-mail.

The web page of the course have a number of self-explanatory buttons at the top to help navigating the site and get necessary information quickly and effectively:
[Course_description], [Lab_descriptions], [Lab_evaluations], [Instructions_for_students], [Instructions_for_instructors], [General_schedule], [Student_assignments], [Presentation_schedule], [How_to_write_report], [Presentation_evaluation_form], [Metric_system], [Average_lab_performance], [Individual_lab_performance].

Communication between the coordinator, TA, students and individual instructors is conducted largely by e-mail; data necessary in some labs are posted on HTTP and/or FTP servers for download; organization of the course and finalizing the schedules for labs and presentations is done via e-mail and web postings. Thus, this course also trains students in using electronic communications extensively. The only exception is the lab reports. They are to be submitted on paper, mainly due to the necessity of deadlines and time flow of the course.

Strict policy on deadlines

Another important feature of the course is very strict policy on deadlines. To be fair, we should emphasize that this policy is combined with relatively forgiving schedule of the labs and report deadlines.

The typical 'unit' of the course is a complex of activities associated with a single lab, as illustrated below:

- week 1: prelab;
- week 2: lab week (each student attend a lab at one assigned day);
- week 3: postlab;
- week 4: reports are due exactly one week after the postlab; then they are delivered to the lab instructor for grading and comments;
- week 5: reports are back from the instructor.

The deductions for late lab reports are made at a rate of 10% per day. We believe that these measures, although sound severe, actually exert positive influence on students and help in the timing of the course. First, it allows to keep course within planned timeframes, Second, students learn quickly that the full scale report requires substantial efforts to finish, and cannot be done the last night before the deadline. Third, students are getting a little bit of discipline and organizational skills.

Conclusion

EBME 313/314 "Biomedical Engineering Laboratory I/II" course has a complex structure, and requires a lot of attention from the coordinator, TA, students, and lab instructors. In return, students are getting a diverse body of knowledge and skills. EBME 313/314 is not just a set of educational labs. Instead it naturally combines various components: from educational lectures (data analysis, pre- and post labs) to real life experiments on real scientific equipment, from ethics discussions to maintaining a discipline, from writing a scientific style reports to computer-based presentations.

According to the numerous feedbacks from students, EBME 313/314 "Biomedical Engineering Laboratory" is considered one of the best courses in the BME curriculum, along with EBME 201/202 "Physiology and Biophysics".

The summary of course evaluations by students during last few years (% of replied):

Semester	Component	Excellent	Very good	Good	Fair	Poor	N/A
Fall 1998	Course:	7	31	28	24	7	3
	Instructor:	3	24	21	28	7	17
	TA:	21	38	21	10	7	3
Spring 1999	Course:	11	22	52	7	4	4
	Instructor:	7	41	37	7	0	7
	TA:	19	44	19	7	0	11
Fall 1999	Course:	0	44	38	19	0	0
	Instructor:	0	44	56	0	0	0
	TA:	19	31	25	25	0	0
Spring 2000	Course:	29	71	0	0	0	0
(no TA)	Instructor:	29	57	14	0	0	0
	TA:	-	-	-	-	-	-
Fall 2000	Not available						
Spring 2001	Course:	0	78	22	0	0	0
	Instructor:	0	67	22	0	0	11
	TA:	0	44	22	11	0	22

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