Session 1309

Design and Implementation of an Introductory Bioengineering Course for EC2000

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Introduction

The Arizona State University course BME201 – Introduction to Bioengineering has been developed and refined in recent years using an innovative team instruction format and modular structure that is well suited not only to the traditional role of such a foundation course of introducing students to the Bioengineering field (and its range of sub-disciplines and career directions), but also to the evolving challenge of forming and strengthening students' knowledge and training in Bioengineering across the multitude of required ABET EC2000 abilities[1]. This paper describes the philosophy, design, implementation, assessment and evaluation of BME201 with a particular emphasis upon the success of this course in early promotion of student achievement and success within an overall curriculum that has recently passed through its first round of reaccreditation review under EC2000.

The Undergraduate Bioengineering Curriculum at Arizona State University

The B.S.E. Bioengineering degree program at ASU has been accredited continuously through ABET (the Accreditation Board for Engineering and Technology) since 1985. The program was most recently site visited for reaccreditation in November of 2003 for the first time under the revised ABET Engineering Criteria 2000 (EC2000) for the 2003-2004 cycle[2]. Enrollment in the degree program has grown steadily over time and stands at over 450 students in the current academic year with a gender balance that reflects that of the general population. The B.S.E. Bioengineering degree is a traditional four-year 128 credit hour program of study taught via a semester system. One section of the three credit-hour course BME201 is offered each fifteen-week semester (fall and spring) with current section sizes of approximately 60 to 70 students (class meetings twice a week for 1.25 hours per class). In the last four years, seven different Bioengineering faculty have instructed or co-instructed the course (typically in pairs of faculty each semester with differing expertise). Two of the authors of this paper (Sweeney, Panitch) have been the most regular instructors over this time and the remaining author (Cullen) has served as a critical teaching assistant over multiple semesters.

Mission and Goals of the Bioengineering Degree Program

The mission of the Bioengineering Program at ASU is to educate students to use engineering and scientific principles and methods to develop instrumentation, materials, diagnostic and therapeutic devices, artificial organs, or other equipment and technologies needed in medicine and biology and to discover new fundamental principles regarding the functioning and structure of living systems. The overall goal of the program is to produce high-quality graduates with a broad-based education in engineering and the life and natural sciences who are well prepared for further graduate study in bioengineering, a career in the medical device or biotechnology industries, a career in biomedical research, or entry into a medical or other health profession school.

Educational Objectives

The program's mission is achieved by having its faculty and instructors fulfill the following educational objectives (consistent with EC2000 Criterion 2):

- To provide students with a strong foundation in mathematics, the physical and life sciences, and basic engineering; and to give students a balance of theoretical understanding and ability in order to apply modern techniques, skills, and tools for problem solving at the interface of engineering with the biological and medical sciences.
- Students demonstrate an ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and nonliving materials and systems.
- Students are able to design systems, devices, components, processes, and experiments with an understanding of manufacturing processes to meet real-world needs for solutions to problems in the biomedical device industries, medicine, and the life sciences.
- Students are able to communicate effectively as bioengineers in oral, written, computer-based, and graphical forms.
- Faculty seek to instill students with a sense of commitment to professionalism and ethical responsibility as bioengineers.
- Students are given opportunities to interact with and gain real-world experience with local and national medical device and technology industries, health-care organizations, educational institutions, and constituent populations.
- Faculty seek to develop within students an understanding of and positive approaches toward continued lifelong learning of new technologies and relevant issues in the discipline of bioengineering.

These educational objectives are fulfilled through student achievement of twenty-four related program outcomes, which also insure that the eleven outcomes of ABET EC2000 Criterion 3 (the familiar '3a through 3k') and the three main elements of Criterion 8 for Bioengineering programs (referred to in this paper as '8a, 8b, and 8c') are achieved as well. Along with the Criterion 4 Professional Component, the requirements of Criteria 3, 4 and 8 can then be summarized for the purposes of this paper as:

- (3a) An ability to apply knowledge of mathematics, science, and engineering
- (3b) An ability to design and conduct experiments, as well as to analyze and interpret data
- (3c) An ability to design a system, component, or process to meet desired needs
- (3d) An ability to function on multi-disciplinary teams
- (3e) An ability to identify, formulate, and solve engineering problems
- (3f) An understanding of professional and ethical responsibility
- (3g) An ability to communicate effectively
- (3h) The broad education necessary to understand the impact of engineering solutions in a global and societal context
- (3i) A recognition of the need for, and an ability to engage in life-long learning
- (3j) A knowledge of contemporary issues
- (3k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
- (4) Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political.
- (8a) An understanding of biology and physiology
- (8b) A capability to apply advanced mathematics, science and engineering to solve problems at the interface of engineering and biology
- (8c) An ability to make measurements on and interpret data from living systems, addressing the problems associate with the interaction between living and non-living materials and systems

History, Design and Implementation of BME201 – Introduction to Bioengineering

BME201 – Introduction to Bioengineering is nominally the first course in the major taken by ASU students, typically in either semester of the sophomore year of study (although it is not uncommon for some students to delay taking the course until their junior year, and some Freshman students are also able to take the course with sufficient Advanced Placement or college credit from high school in English composition). First introduced to the required curriculum in Bioengineering in 1996, this course fulfills the ASU 'Literacy' requirement (which dictates a strong emphasis on development of writing and oral communication, as well as critical inquiry skills) and has the basic pre-requisite of one full year of college level English composition coursework. To maximize flexibility for student enrollment, no other prerequisites are listed. However, sophomore level students in the Bioengineering major typically have progressed into their second year of calculus and differential equations, have completed their required year of physical chemistry, are currently taking their first or second semester of calculus-based physics, have taken or are taking a first college level course in Biology, and may have already progressed into their first engineering core classes such as Statics and/or Electrical Networks I. Students will also normally have completed ECE100 – Introduction to Engineering, which besides laying the basic foundation of engineering problem solving also provides an introduction to engineering design, teaming, and the use of basic computational and analysis software tools such as Microsoft Excel. The course is delivered recognizing that students will typically have a range of levels of preparation in mathematics, the sciences and engineering, and in fact student teams are encouraged to take advantage of this diversity of preparation and experience levels.

The highest-level course objectives of BME201 are that by the end of each semester students should possess:

- A greater appreciation for the breadth of studies under the bioengineering umbrella
- A focus on the area of their interests as they define their educational goals
- An introduction to bioengineering labs and confidence in performing a lab
- Competence in technical writing and an introduction to the writing of lab reports
- An ability to assemble a poster presentation and an understanding of their importance in conveying science and technological findings to their community

As such, the course objectives most strongly support student achievement of the program outcomes strongly linked to the ABET outcome 3g (communication effectiveness), and outcome 8c (make measurements on and interpret data from living systems). In addition, the course places a heavy weighting upon forming students into effective teams that then carry out labs, exercises, and the majority of their writing in groups of four or five students through the five technical 'modules' of the course. Achievement of outcome 3d (functioning in teams) is therefore promoted, albeit not in "multi-disciplinary" teams per se.

As detailed further below, the modules of the course provide an introduction to five main areas of the Bioengineering discipline. It is explained to students in the course introduction that this composition of modules is by no means exhaustive, and the content of the modules has in fact been adapted over time and to some extent is left up to the current instructors in a given semester. Instruction in the course is normally accomplished with pairs of core faculty members from diverse expertise (e.g. Sweeney – bioelectricity, neural prosthetics, cardiovascular devices, computational modeling; Panitch – biomaterials and biotechnology; molecular and cellular engineering) in order to best assist in delivery of a wide breadth of material. Within the central two class periods of each module (normally structured in the four class periods over a two week period of time with an introductory lecture, an in-class exercise, a mini-lab, and a wrap-up guest expert lecture or panel) the class body splits in half, with one half carrying out the mini-lab (with one instructor) and the other half carrying out an in-class exercise (with the other instructor). In the other class period within the center of the module, students then carry out the converse task (mini-lab or class exercise). This unusual delivery of the course enables the instructors to work with a more manageable number of student groups in both labs and exercises (typically eight or nine groups instead of sixteen to eighteen), facilitating a more active learning environment. In-class exercises often incorporate an open-ended problem component and/or design tasks, providing an early introduction in the major to elements of ABET outcomes 3a (apply math, science and engineering), 3c (design systems, components, processes), 3e (identify, formulate, solve engineering problems), and 8b (solve problems at the interface of engineering and biology). Another important element of course delivery is the involvement of alumni and other local industrial and/or research experts through guest lectures and panels (usually in the class time slot at the end of each module). Guests are encouraged to discuss their career paths and responsibilities (promoting ABET outcome 3f and Criterion 4), in addition to delivering a focused lecture and/or discussion that wraps up the module.

At the completion of each module an individual (in Module 1) or team (Modules 2 through 4) written Technical Report or Poster Presentation (for Module 5) is due. As Litzinger has reported[3], writing assignments can be utilized well in engineering courses to help focus and refine student learning and skills for life-long learning, ethics, and the global context of engineering. We have used a similar strategy with modular Technical Reports to promote ABET outcomes and criteria pertinent to Bioengineering. Each report or poster must contain at least four required sections (authored by each member of the team) on a focused topic pertinent to the module. These include: a technology overview (usually pertinent to ABET outcomes 8b and/or 8c); the biological and/or medical problem(s) addressed by the technology (ABET outcome 8a); a section reporting on the module experiment carried out by the team (ABET outcome 8c); and a critique on the social and ethical issues pertinent to the technology (ABET outcomes 3f and/or 3h and/or 3j; Criterion 4). Each group chooses the overall topic for their technical report or poster based upon brief Topic Exploration papers written and submitted by each member of the team earlier within each module. Through these exploratory papers, as well as through training in the appropriate and effective ways to perform literature searches (especially through web-based electronic resources) approaches to and appreciation of life-long learning are promoted (ABET outcome 3i). The final "exam" in the course is a poster presentation prepared by each student (or pairs of students) on an additional topic in Bioengineering of their choice and scored by the course instructors and teaching assistants, as well as invited guest judges (usually former BME201 instructors and assistants). This final poster contains, in addition to the same sections required in the module Technical Reports, a career section (instead of an experimental section) reporting on an interview (conducted in person or by email) of an individual working in an area pertinent to the poster topic (promoting ABET outcome3f and/or Criterion 4). In that BME201 is normally the first course taken in the major, ABET outcome 3k (use the techniques, skills and modern engineering tools necessary for engineering practice) is at best only addressed at a very introductory level.

In a typical semester offering then, BME201 normally includes the following detailed content (with references in parentheses to the typical topic instructor; and the ABET EC2000 criteria/outcomes which are supported through student learning, experiences, and exposure to potential career paths and models of professional practice):

- Beginning of Semester
  - Introduction to the course (course instructors)
  - History and overview of the field of Bioengineering (guest faculty; 3h)
  - Bioengineering and the Bioengineering curriculum at ASU (course instructors)
    - Includes career planning survey and pre-course student self-assessment (4)
    - Includes focus on ABET and benefits of accreditation
    - Includes promotion of student research opportunities and internship programs (4)
  - Introduction to Technical Writing in the discipline (guest English faculty; course instructors; 3g)
    - Includes writing as a group (3d)

        - Includes mini-lab documentation methods and expectations (3b)
        - Includes best practices for performing literature searches, use of the internet and Writing Center tutors (3i) as well as plagiarism in technical writing (3f, 4)
    - Introduction to issues of diversity at the university and in the workplace (guest diversity training expert; 3f, 3j)
        - Includes focus on diversity considerations in team dynamics and productivity (3d)
- Module 1: Medical Devices and Diagnostics (includes individual topic exploration, and individual report)
    - Introduction to Artificial Organs and Medical Devices (guest faculty; 8a, 8b, 8c)
    - In-Class Exercise: Introduction to Bioethics with group activity (course instructor; 3f, 4)
    - Mini-Lab: Dialysis and basics of mass balance/transfer (course instructor; 3a, 3b, 3d, 8a, 8b, 8c)
    - Medical Diagnostics: Focus on Medical Imaging (guest MRI research expert; 3a, 4, 8a, 8b, 8c)
- Module 2: Biomechanics and Rehabilitation Engineering (includes individual topic exploration and group report)
    - Introduction to Biomechanics (guest faculty; 8a, 8b, 8c)
    - In-Class Exercise: Rehabilitation Engineering group design activity (course instructor and guest expert; 3a, 3c, 3d, 3e, 8b)
    - Mini-Lab: Wheelchair experience with activities of daily living (course instructor; 3b, 3c, 3d, 8b, 8c)
    - Biomechanics: Focus on Orthotics and Prosthetics (guest Orthotics/Prosthetics practitioner and biomechanist; 3a, 3c, 4, 8a, 8b, 8c)
- Module 3: Biotechnology (includes individual topic exploration and group report)
    - Introduction to Biotechnology including molecular, cell and tissue engineering (course instructor or guest faculty; 8a, 8b, 8c)
    - In-Class Exercise: Tissue engineering group design activity (course instructor and/or guest expert; 3a, 3c, 3d, 3e, 8a, 8b, 8c)
    - Mini-Lab: Enzyme experiment (instructor; 3a, 3b, 3d, 3e, 8a, 8b, 8c)
    - Biotechnology: Focus on entrepreneurship in bioengineered products and pharmaceuticals (guest expert and/or instructors; 3a, 3c, 4, 8a, 8b, 8c)
- Module 4: Bioelectricity
    - Introduction to Bioelectricity (course instructor or guest faculty; 8a, 8b, 8c)
    - In-Class Exercise: Design of the ‘ Year 1901 stimulator’ group activity (course instructor; 3a, 3c, 3d, 3e, 8a, 8b, 8c)
    - Mini-Lab: Human Electromyogram acquisition and analysis (course instructor; 3a, 3b, 3d, 3e, 8a, 8b, 8c)
    - Bioelectricity: Focus on implanted stimulation, pacing and defibrillation devices (guest expert; 3a, 3c, 4, 8a, 8b, 8c)
- Module 5: Biomaterials (includes individual topic exploration and group poster presentation)
    - Introduction to Biomaterials (guest faculty; 8a, 8b, 8c)
    - In-Class Exercise: Biomaterials selection group design activity (course instructor; 3a, 3c, 3d, 3e, 8a, 8b, 8c)
    - Mini-Lab: Hydrogel synthesis experiment (course instructor; 3a, 3b, 3d, 3e, 8a, 8b, 8c)

- Biomaterials: Focus on cardiovascular devices and implants (guest expert; 3a, 3c, 4, 8a, 8b, 8c)
  - Includes introduction to biomedical product manufacturing and standards/regulations (4)
- End of Semester
  - Introduction to the FDA and regulatory requirements in bioindustry (guest expert; 4)
  - Overview of career choices and planning in Bioengineering (course instructors; 4)
    - Includes preparation for careers in the medical device and biotechnology industries, and preparing for graduate, medical, law or business schools
  - Final individual or paired poster presentations (judged by course instructors and guest judges; 3f, 3g, 3h, 3i, 3j, 8a, 8b, 8c)
    - Includes career interview (4)

Assessment and Evaluation

An anonymous student pre- and post-course self-assessment survey has been used in the course since the fall semester of 2000 to assess and evaluate changes in students' ratings of the importance of obtaining the range of EC2000 required skill sets, as well as self-ratings of understanding or experience in building their Bioengineering specific skills. While student self-assessment data is certainly not sufficient by itself for the purposes of EC2000 outcomes-based assessment, it has served as an informative starting point for evaluation and continual refinement of the BME201 course. The strong emphasis of the course on written reports and documentation has also lent itself readily to the evidence requirements of Criterion 3 that include "student portfolios" (including electronically submitted report and poster materials).

Across all available pre- and post-class student self-assessment data from the fall 2000 to the fall 2003 semester offerings of BME201, for example, student overall ratings of the importance to them of obtaining the following abilities, experiences and/or skills prior to their graduation all showed significant increases (Mann-Whitney U-Test on Likert scale data; $p<0.05$) through the semester in which they took BME201:

- Development of hands-on engineering skills
- Ability to communicate effectively (in both oral and written form)
- Knowledge and understanding of Bioengineering as a profession
- Development of teamwork and interpersonal skills
- Learning how to learn skills (skills for lifelong learning)
- Practical experiences with research (summer research experiences)
- Practical experiences with health and medicine

Corresponding statistical analysis of available fall 2000 to fall 2003 student self-assessments of their pre-class versus post-class levels of understanding, knowledge or experience across a number of topics also indicates significant improvements in the following areas:

- Understanding of the career options available in the field of Bioengineering
- Understanding of the variety of emphasis areas available in Bioengineering

- Awareness of the area of Bioengineering of most interest to the student
- Experience in performing Bioengineering labs
- Confidence in performing Bioengineering labs
- Experience in writing technical reports
- Experience in using computer-based skills
- Confidence in oral communication of technical subject matter (particularly in Bioengineering)

Students are also encouraged to provide their thoughts on the strengths and weaknesses of the class in their post-assessment surveys. Students often comment on their pleasure in being exposed to such a range of topics and experiences in the field through the course. The mini-lab experience is often also highlighted by students in comments, both for the challenge of preparing for and carrying out labs within the limited 1.25 hours of each lab meeting, but also for the value of obtaining lab experiences in the major at such an early stage of the curriculum. The involvement of numerous guest lecturers and panelists, many of who are alumni of the program and/or local experts with degrees or experiences in Bioengineering, is praised by the students each semester. For example:

"Love the guest lecturers! Makes the class exciting and gives students an early chance to learn which way they may want to direct their career" (Spring 2002 student)

In response to regular student comments that they have wished that they could take BME201 as early in the curriculum as possible (i.e. earlier than the sophomore year where it is now placed), the course will become BME101 starting with the fall 2004 offering and will be best taken in the second semester of the freshman year (with adaptation of the course requirements so that the second semester of English composition will become a co-requisite rather than a pre-requisite).

References

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Biographical Information

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HEATHER CULLEN has been involved as a teaching assistant for BME 201 since August 2000. She earned her B.S.E. in Bioengineering degree from Arizona State University in May 2000 and is currently pursuing her M.S. in Bioengineering.