AC 2007-2580: TEACHING BIOENGINEERING TO FRESHMEN AT UCSD

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Teaching Bioengineering to Freshmen at UCSD

Abstract

Several courses are now offered at UCSD in order to introduce freshmen students to Bioengineering. BENG 1, Introduction to Bioengineering, is designed to introduce students to bioengineering as a discipline and also to introduce them to the research activities in the department in a large lecture-style course format. Bioengineering faculty members speak about their research during the class sessions and teams of students explore a design project of their choice. BENG 87, Freshmen Seminars in Bioengineering, is offered to introduce students to aspects of bioengineering in a small interactive group setting with faculty. Faculty members offer seminars each quarter on topics of their choice, usually related to their research interests. Students select seminars on a topic of interest and are encouraged to share their ideas with faculty and other students during discussions. Both courses have proven to be successful in format and content. Students enjoyed the variety of topics that were presented, met the department faculty at an early stage, and were assisted in picking an area of focus within bioengineering. Since these courses were pass/fail, the students did not feel pressured at a vulnerable time in their college career, when they are transitioning to the demands of college courses. Group design project gave the students some experience with working on teams and performing background research necessary for research, and prepared them for other courses.

Introduction

The bioengineering program at UCSD was founded in 1966 with an emphasis on biomechanics and microcirculation. It was established as a joint effort between the Department of Applied Mechanics and Aerospace Engineering and the School of Medicine. Initially, there were no specific courses offered in bioengineering, and undergraduate students took courses in math, physics, chemistry, biology, physiology, fluid mechanics and continuum mechanics to fulfill the major requirements. The formal Department of Bioengineering was established in 1994 with a growing undergraduate enrollment which is now ~1,000 students. Students can choose amongst four majors, *Bioengineering*, *Bioengineering: Biotechnology*, *Bioengineering: Premedical*, and *Bioengineering: Bioinformatics*. The *Bioengineering* and *Bioengineering: Biotechnology* majors are accredited by the Accreditation Board of Engineering and Technology (ABET). Because of the rapid growth in student entry into the Department as well as the breadth of career pathways, it was recognized that there was a need for students to be introduced to the Bioengineering faculty and research early in their academic career.

This need is well-established, and arises out of the need to satisfy student curiosity about the bioengineering discipline, to provide students with information about the department, and to instill in students the beginnings of much-needed technical survival skills. These first year courses can improve academic performance, stimulate interest and improve retention, and better prepare students for future coursework[1-3]. It is important that students acquire the qualities that prepare them to be successful engineers in the changing workplace, including the ability to work on and communicate with members of a multidisciplinary and professional team[4-7]. Developing familiarity with the profession enables students to decide whether their chosen major is well-

suited to their individual aptitudes and interests and can, in turn, decrease student attrition and the length of time to graduation.

Several programs offer freshmen courses, some focused on non-technical freshmen survival skills such as time management and study skills[8-13] and some focused on skills necessary to directly address ABET criteria[14, 15]. Others, such as the freshmen Bioengineering courses offered at UCSD, strive to be more flexible[12, 16, 17], offering courses that peak student interest, that are minimal in time commitment, and help students establish relationships with faculty early on[18, 19]. Such course offerings allow students and faculty to participate in the courses out of interest and provide students with more intimate intellectual contact with faculty and fellow students and earlier exposure to engineering innovations, design, and problem-solving[20]. Two of these courses which are integrated into the UCSD Bioengineering curriculum are described here.

In response to the need for freshmen-level bioengineering courses, the Department of Bioengineering instituted BENG 1, Introduction to Bioengineering, in the Spring of 1996 and BENG 87, Freshman Seminars in Bioengineering, in the Fall of 2003. These courses fulfill in the UCSD Bioengineering curriculum, the need for students to be introduced to Bioengineering faculty and research at a time when they do not take Bioengineering courses. In the UCSD Bioengineering curriculum, students take general math, physics, chemistry and biology courses during their first year, with BENG 1 and BENG 87 being their only means of being introduced to bioengineering as a discipline. While it is important for students to form a solid foundation in math, physics, chemistry, and biology before delving into the advanced engineering and bioengineering courses, it is important that students, early on in their academic career, interact with Bioengineering faculty and learn about current bioengineering research topics. Taking these courses also provides undecided students with information about Bioengineering as a career at an early stage when they might want to switch majors.

BENG 1 is a required course for completion of the Bioengineering degree and is designed to introduce students to bioengineering as a discipline and also to introduce them to the research activities in the department. Typical enrollment is 250 students, and the class meets for ten 80 minute sessions. During each class session, two Bioengineering faculty members speak for 20 minutes about their research, and this is followed by questions from the students. In the first class, students are asked to submit a one page report in one week on any bioengineering project of their choice. This provides the instructor with the students' conception of bioengineering. Later in the course, students are asked to form groups of 4, select a project, and proceed with literature research, working towards producing a 4 page report by the end of the quarter. In the third and fourth week of the course, the library resources center provides small groups of students a course on literature research. Six student groups are chosen to make a 10 minute presentation of their project during the last lecture.

BENG 87 is an elective course and is offered to introduce students early to aspects of bioengineering in a small interactive group setting with the faculty. Enrollment is limited to 20 students, and the class meets for a total of 8-10 hrs over a ten-week quarter. Faculty members offer seminars each quarter on topics of their choice, usually related to their current research. While seminar content varies, often students are asked to perform literature research and contribute to the seminar discussion based on what they find.

One of the purposes of these courses is to introduce all the Freshmen Bioengineering students to each of the full-time Bioengineering faculty members. Each faculty member is invited to present perspectives on Bioengineering, typically within the context of their research area. This often stimulates subsequent interaction between undergraduate students who seek involvement in academic research at an early stage, as well as interactions between undergraduate students and faculty on class research and design projects that the students undertake at various stages in their coursework. The general goals of these courses are for the students to obtain a better understanding of what a Bioengineer does, to diversify their knowledge of Bioengineering research topics, and to meet a potential academic and professional mentor.

The courses also give students an early and basic introduction to topics important for the achievement of Bioengineering program objectives and for their future success as a Bioengineer. The overall mission of the Bioengineering program at UCSD is to provide students with an excellent education that enables successful, innovative, and lifelong careers in bioengineering industries and professions. The overall educational objectives are to provide students with a modern bioengineering education, consisting of depth, breadth, and creativity in the central areas of bioengineering, its underlying sciences, and related technologies; effective communication, learning, and teamwork skills that facilitate bioengineering practice, continued professional advancement, and adaptation; and a recognition of professional and social responsibilities, including sensitivity to ethical and health-related issues. In BENG 1 and BENG 87, the students get an early introduction to how the fundamentals of the basic sciences can be applied to current Bioengineering research. Students also obtain their first introduction to written and oral communication skills, as well as research skills, necessary for a successful bioengineering career. Finally, these courses provide a forum for the discussion of the importance of Bioengineering research on a societal and global context as well as the professional and ethical responsibilities bioengineers have due to the societal and global implications of their research.

The objectives of this paper were to describe BENG 1 and BENG 87 in terms of the course topics, format, assignments, and grading, and to assess the effectiveness of these courses. These courses differ in student enrollment, course format, and course topics and are discussed individually below. The courses were evaluated based on student satisfaction and student progression subsequent to taking the courses.

Methods

BENG 1

BENG 1 serves as an introduction of the Bioengineering faculty and their research to the freshmen. The class is offered in the winter quarter and meets once a week. It is a one unit pass/no pass class. There are 3 instructors, 2 graduate student TAs and six upper division undergraduate TAs assigned to teach this class. Students are encouraged to interact with the TAs because in many cases the TAs, especially the undergraduate ones, know better what the students want. During each lecture two faculty members from the department will present their interests and research areas. In addition to scientific research topics, lectures are included that deal with

ethics, entrepreneurship, industrial relationships and socioeconomic issues. Listed below is the topics list for the 2007 class:

- *Blood Substitutes and the Design of Oxygen Non-carrying and Carrying fluids.*
- *Medical Devices: Saving and Improving Lives.*
- *Introduction to Stem Cells.*
- *The Nanoscale Nervous System and Engineering Approaches for Interfacing with it.*
- *Network Biology.*
- *Finding the Origin of Inflammation: The Key to Disease Prevention.*
- *Engineering Gene Circuits.*
- *Bioengineering Solutions for the Treatment of Heart Failure.*
- *Bioinformatics and Systems Biology: Obtaining the Design Principles of Living Systems.*
- *Ethics in Science and Engineering.*
- *Microelectronics Arrays: Applications from DNA Hybridization Diagnostics to Directed Self-Assembly Nanofabrication.*
- *Entrepreneurship in Bioengineering.*
- *Microvascular Changes in Diabetes.*
- *Bioengineering Cartilage and Joints.*
- *Systems Biology: A Four Step Process.*
- *Bioengineering in the New Century.*

Faculty presenters are asked to post a copy of their presentation and a representative manuscript of their work on WebCT. Those serve as references for students to investigate the topic further. The students are also required to sign up for a special library workshop designed for BENG 1 to show them the library resources and how to search for references. In 2001 a book, "Introduction to Bioengineering," based on the lecture materials was published[21]. It is being used as the textbook for students in BENG 1. A new version of the book is planned for the 2008 class.

Because an engineer's job is to invent and design, students are encouraged at this early stage to start thinking about an instrument, device, or a technology that they want to develop. Bioengineering is not defined at this time in order to give the students flexibility in defining a design project to explore. To this end, they are required to work on a series of assignments which emphasize ingenuity and team work. They are requierd to turn in a group project at the end of the course and six projects are selected to be presented during the last lecture of the course. The series of assignments that students have to complete during the course are meant to culminate in the final design project report:

- Assignment #1: each student selects a bioengineering design problem of interest and discusses its importance.
- Assignment #2: students organize into teams of four and select a design problem of mutual interest.
- Assignment #3: students perform literature research about the chosen project.
- Assignment #4: students report the science behind the design and include design illustrations.
- Assignment #5: students discuss the feasibility of their design.
- Assignment #6: students prepare a final report in a scientific report format.

This course encourages team-work, including collaboration on assignments and referencing of help from others.

BENG 87

The purpose in offering the bioengineering freshman seminar BENG 87 is to increase student-faculty interaction and to introduce students to focused topics important to Bioengineering research. There was a need to increase student-faculty interaction at an early stage in student training, especially in the first and second years of college when they take few, if any, Bioengineering courses. BENG 87 and BENG 1 as the only lower division Bioengineering courses offer the students their first glimpse into Bioengineering research. BENG 87, the freshman seminar, is meant to be a means for student-faculty discussion in an informal setting. This course format provides students with a focused discussion of a current topic important in Bioengineering. Students are not required to take a seminar course to complete the Bioengineering degree and receive 1 unit of credit for taking BENG87.

The Bioengineering freshman seminar can be taught by the instructor lecturing to the students or by the instructor leading discussion of the educational topic. The teaching style can vary from session to session with preference being up to the instructor. Enrollment is limited to fifteen to twenty students, with preference given to entering freshmen; of the nineteen BENG 87 seminar courses offered since the Fall of 2003, the average starting enrollment has been 15±1 (mean±stdev). The small number of students allows close interaction between the students and faculty, and because of this, the course is generally run as a discussion between faculty and students. Usually faculty encourage discussion and student interaction, whether by asking questions directly to the students or by having students contribute information or questions they have found through their own independent research or through their assignments.

The overall expected course outcome from these intimate seminar discussions is that students can independently research and competently report or discuss a Bioengineering topic of interest. The overall general educational objective of the freshman seminar course is to introduce students to Bioengineering as a discipline, the areas of emphases at UCSD, the faculty members of the Department of Bioengineering at UCSD, and their interests and achievements. The specific educational objective may vary depending on the educational topic of the course and have ranged from instilling in students an ability to write a research proposal to provide students with a solid foundation in a particular area of research. The educational objectives and topics vary with the diversity of the faculty within the Department of Bioengineering. While the educational objective is not restricted by the University, seminar courses offered within a particular department must relate to the educational objectives of the department, must require only 0-2 hours of work per week, and must be approved by the chair of the department as having freshman level material.

Topics covered in the seminar course can vary greatly and are selected by the faculty teaching the course. Generally, if the seminar covers a single area of research emphasis, it is a research topic in which the faculty is a specialist. Seminars can vary in overall emphasis,

whether focused on a single research topic, on how to write a research proposal, or on how to perform research. Examples of topics covered in past seminar courses are

- the bioengineering problem definition (e.g. a device for clinical application, an instrument for scientific inquiry, a study of a phenomenon of interest to bioengineering) and design objectives,
- the design approach (incorporation of available knowledge and establishing a scientific basis),
- the definition of the significance of the design (how will a successful design impact a patient and the global community),
- the search for information relevant to a design project (what designs have been proposed in the past, have they been successful, and what is the most current information available in that research field that might improve the design),
- the communication of the design with careful drawings, reports, and presentations,
- the development of the analysis of the design with equations and mathematical descriptions,
- and the analysis of feasibility of the design (what are the important factors of the design, what are the strengths and weaknesses of suggested designs, how are the designs tested, are animal or human experiments needed and what are the ethical considerations behind this, are there governmental and university regulations regarding such experiments).

Having such a variety of course topics allows students to choose one that peaks their intellectual curiosity and gives them the ability to share their ideas with a faculty member with expertise in that field.

The course provides interested students with knowledge of current Bioengineering research topics and how that research requires a foundation in the basic sciences, mathematics, computation, and the more specific disciplines of biomechanics, biotransport, bioinstrumentation, bioelectricity, biosystems, and/or biomaterials. Students attend the seminars of interest to them and complete assignments that promote learning about Bioengineering problem specification and design as well as hypothesis formulation and data interpretation.

Assignments and feedback given during the course can vary, as well, depending on the educational objective of the course. In past courses, the main topics have varied from searching for and reading relevant literature to writing a research proposal. Because the course is graded on a pass or no pass basis, students must simply complete the assignments to a satisfactory level in order to receive a passing grade. At this early stage in their educational career, freshmen students are adjusting to their first year of general courses, but, in many cases, desire the ability to interact with Bioengineering faculty on a more intimate level and get an education on what is cutting-edge Bioengineering research. The freshmen seminar offers this with little stress on student time and without the pressure associated with graded courses. The University requires that students spend only between 0 and 2 hours per week in these seminar courses reading materials and working on assignments. Because assignments are few, students are able to receive substantive feedback directly from the faculty teaching the course.

Case Studies. Seminar courses taught recently (in the Fall of 2006) included "Bioengineering of Red Blood Cells" and "Undergraduate Research Opportunities in Bioengineering." As an example of how a freshman seminar course is instructed, the course topic, materials, and assignments of each of these seminars are described below.

The seminar, "Bioengineering of Red Blood Cells," was taught as a discussion of very specific topics related to red blood cells or erythrocytes. Topics covered included:

- the ultrastructure of the skeleton of the human erythrocyte membrane,
- an introduction to embryonic stem cells,
- an introduction to hematopoietic stem cells,
- the hematopoietic commitment during embryonic stem cell differentiation,
- and the use of genetically modified stem cells in the study of modifications to the erythrocyte membrane.

For each of the topics, appropriate journal articles or internet resources were provided. Assignments were to read the appropriate material and to ask questions during the discussion session. Students reviewed the information prior to the start of the respective seminar discussion session and were expected to participate in discussion of the topic by presenting the information to fellow students or asking questions about the topic. Students were expected to participate to a moderate extent to receive a passing grade.

The seminar, "Undergraduate Research Opportunities in Bioengineering," was a course introducing students to research opportunities in bioengineering and how to find them as well as how to write a research proposal. Course topics included:

- undergraduate research opportunities in bioengineering,
- recent developments in Bioengineering nationwide and in the State of California,
- conceptual approaches and research goals,
- ethics and conflict of interest
- how to prepare and plan,
- where to look for opportunities.

During each session students were given research articles that were discussed to highlight the elements of a research proposal. More senior undergraduate students were also invited to the seminar to talk about their experiences in completing a research project as an undergraduate. Throughout the course students learned about how to write an independent research proposal using all of the major elements required to achieve industrial or basic science research goals. Each element was discussed in detail including the Introduction and Background, Objectives, Specific Aims, Materials and Methods, Results, Discussion, and References. Throughout the course students were to independently and gradually complete their own research proposal which was presented at the end of the course. Completion of the proposal was required to receive a passing grade for the course.

Results

The success of these courses can be evaluated in many ways, including student opinion surveys, which at UCSD are termed the course and professor evaluation system (CAPE). The

success of these courses can depend on several factors including if the course is taught well by the instructor, if the course is a topic of interest to the students, if student participation was encouraged, and if the students found it stimulating.

When BENG 1 started in 1996 as an elective the enrollment was 23 students. There were 120 students in 1997 when it became a required course, and the enrollment steadily increased to 250 in recent years. Most of the students surveyed who had taken BENG 1 between 2003 and 2006 enjoyed the diverse and numerous topics presented, finding them intellectually stimulating (76±7%). Many students would recommend the class in the future (74±6%). However, some students commented that some of the materials were too difficult to understand at the freshman level. In addition, because they only received 1 credit for the course, they felt the work load related to the design project was high. However, many others found it challenging and appreciated the opportunity to get involved in a project at such an early stage. The average time spent on this class as determined from the surveys was minimal at 1.8±0.6 hours per week.

Of the students who had taken one of the eight BENG 87 seminar courses surveyed through CAPE between the Spring of 2003 and Spring of 2006, 98±2% felt the instructor had a strong command of the material and 86±4% felt the instructor taught the material well. Students also felt the professor promoted relevant questions and discussion (93±3%) and that the professor showed concern for their learning (88±4%). A majority of the students found the topic of discussion stimulating (94±2%), felt they learned something from the course (86±6%), and would recommend the course in the future (95±3%).

Student retention throughout the duration of the course is another index that may reflect student satisfaction with the course. Student enrollment during the BENG 1 courses offered between 1996 and 2006 remained high (95±5%). However, this value may be high because BENG 1 is a required course. Of the nineteen BENG 87 seminar courses offered since the Fall of 2003, the retention of students in the seminars has been high (93±2%). The seminars are usually attended by highly motivated students who desire, in addition to the general education they receive in their freshmen years, an introduction to bioengineering whether to better define their own goals or to learn how research is conducted. These individuals are what make the courses successful.

Another indicator of the success of such courses is the retention of Bioengineering students within the major who have taken the course versus those who have not. Of the 1,354 students who had taken BENG 1 between 1997 and 2006, 71% remained Bioengineering majors three years into the program. Of those who did not take BENG 1 (623), only 9% remained as Bioengineering majors. This is a difficult measure to compile for BENG 87 courses because the number of students enrolled in the course is limited. When the first series of courses were offered in the Fall of 2003, many of those first-year students have just completed their third year. Of the 99 students who have taken a BENG 87 seminar since it was first offered, 71 have remained in the BENG program after completion of their first two years of the program. On the other hand, of the 1,878 Bioengineering students who first enrolled between 1996 and 2004 who did not take a BENG 87 course, only 50% remained Bioengineering students. While this may be an indicator that student retention within the Bioengineering majors is improved when students take BENG

87 seminars, the subpopulation of students who have taken a BENG 87 seminar is small and may be an index skewed toward students more dedicated to bioengineering as a future career.

Discussion

Both BENG 1 and BENG 87 have been successful in terms of student satisfaction as well as student retention in the course and in the major. The student satisfaction surveys convey the ideas that the courses are successful in instruction, format, and content. Students upon personal interview have said that they enjoyed the multitude of topics presented and were excited that these were topics of cutting-edge bioengineering research. In addition, because the faculty were invited to speak or volunteered to give a seminar, they seemed to be more approachable. The success of these courses also comes from knowing that the students would recommend the course in the future.

The success of these courses might also be indicated by the percentage of students who have taken one of these seminars and later participated in research as an undergraduate student and the likelihood that these courses helped them select a research mentor and topic. This data is not available now but could be collected and analyzed in the future. Student satisfaction surveys could be modified to include specific questions such as “How likely is it that you will participate in bioengineering research in the future?” and “Did this course help you to select a research topic of interest to you that you will pursue in the future?” Senior students could also be surveyed to determine if they felt that such courses were helpful to them as an introduction to Bioengineering.

There are several concerns regarding BENG 1 based on students’ feedback. Some students found the topics and the presentations of the invited speakers somewhat beyond their comprehension. Presenters are now informed to adjust the material accordingly. There were some complaints regarding the number of assignments because this is only a one unit course. However, the students enjoyed the opportunity to work on a project of their choice, and they valued the interaction and help from the TAs and faculty. Those selected for making the student presentations were enthusiastic and tended to spend an ample amount of time preparing, rehearsing, and polishing their project.

The enrollment cap was reached in several of the recent BENG 87 seminars offered in the Fall and Winter quarters. Because limited enrollment achieves the more intimate interaction between faculty and the students, it is desirable but limits the percentage of students able to take a seminar course. Achieving and maintaining maximum enrollment is an indicator that the course is necessary, and in the future, more seminar courses will be offered each quarter.

Other possible improvements or additions to these courses might be information about career options for bioengineers. This may be very important to those students who are still undecided about the major. Perhaps also useful to these undecided bioengineering students would be lectures including faculty from other areas of Bioengineering or industry representatives who may be able to provide different perspectives in bioengineering as a profession. Further, discussions with upper classmen or members of the student chapter of BMES could help these entering students gain a better perspective of what is required of them as

bioengineering students and serve as a means of providing active mentors who could provide advice on non-technical survival skills such as time management or study techniques[5].

After the interaction with the faculty, students feel free to ask questions and obtain academic and professional advice. This interaction also helps students pick an area of focus within bioengineering in which to do future research. Since these courses are graded on a pass/no pass basis, the students do not feel pressured to maintain their GPAs and participate in discussions of interest to them. Working on assignments and group projects gives them some experience with working on teams and performing background research necessary for research projects, and prepares them for future courses that might require completion of similar projects. These courses provide the introduction to bioengineering that is built upon in subsequent bioengineering courses and provide a solid base in bioengineering research and communication skills for students' future success as a bioengineer.

APPENDIX

BENG 1 Assignments

Assignment No. 1
Embodiment of Your Thoughts on a Design
Describe a design or research project you would like to carry out. This can be an invention of an instrument or device for scientific inquiries, clinical application or home care, or anything else that you think can qualify as being relevant to bioengineering. It can also be a study of a scientific or technological problem concerning a phenomenon of interest to bioengineering. Note that we did not define "bioengineering". Please define it yourself. Most of us have many projects we would like to do at any given time. For the present assignment, make a choice of one, which is your highest priority, one of which you would be most proud of if the project were completed successfully. Explain your project the best you can. Describe what it is, why do you think it is important, and how would you approach it. If the idea is your own, no reference is needed. If the whole idea or parts of it came from another person, or from a journal article, a paper, a book, then you should acknowledge the source with references. If your idea came from a discussion with a friend then recognize his/her contribution in a separate section designated as "Acknowledgment". Never plagiarize! (see note at end of the Assignments) Maximum 2 pages.

Assignment No. 2
Report on team organization and team project
Organize design/research teams. This course encourages team work and you should plan on having 4-5 students in each group. Hold a discussion among yourselves and decide on a topic for the group project. It is best if you can reach a consensus to concentrate on one project. If you decide to go alone, it is OK too. Write down the names of all team members or just your name on the upper right hand corner. 1 page.

Assignment No. 3
Library Search on Team Project
Find relevant references and background to the project. Follow the library format and check with your TA to make sure the references are listed properly. 1 page.

Assignment No. 4
Scientific Basis for the Design & illustration of design
Discuss the scientific basis of your design or research in light of library search. Illustrate your design with drawings and graphs and discuss how your design will be realized in practice. Estimate time needed to accomplish your design. Discuss possible ethnical questions involved. Maximum 2 pages.

Assignment No. 5
Realization of the Design & Feasibility
Discuss the feasibility of your design or research. What are the unknown factors? What may cause your design to fail? What are its strengths? What are its weaknesses? Are animal or human experiments required? Are governmental and university regulations involved? Budget? Maximum 2 pages.

Assignment No. 6
Final Report
Prepare a final report based on all you have written up to this point. Use the following format for the cover page:

a) At top: Final report on BENG1, Introduction to Bioenginering, Instructors' names.
b) At center: Title of your project.
c) The names of all the authors in alphabetical order with corresponding signatures.
d) At bottom: Date submitted.

Beginning on page 2, writ Sections in the following order:

Introduction
Specific Aims
Designs and Analysis
Discussion
References Maximum 4 pages for entire report

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