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An Integrated Approach to Teaching Biotechnology and Bioengineering to an Interdisciplinary Audience*

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Advancements in bioengineering and biotechnology demand interdisciplinary cooperation, yet communication between engineers, scientists, and clinicians is often a limiting factor in developing effective working teams. To simultaneously engage engineering, biology and physical science students in cross-disciplinary training, a graduate course entitled 'Bioengineering and Biotechnology' was introduced at UNC Charlotte. Developed through the combined efforts of a two-member faculty team from Mechanical Engineering and Biology, relevant biotechnology and bioengineering applications lectures that emphasized cross-disciplinary innovations were presented using an integrated team-teaching format, as complements to lectures on fundamental concepts in engineering and biology. An understanding of the interdependence of engineering, biology, and the physical sciences in biotechnology and bioengineering was also achieved using working examples and cooperative learning exercises. The culmination of the course was the student presentations of written final projects. These projects, prepared by two member cross-disciplinary teams, allowed the students to discuss and critically evaluate a bioengineering or biotechnology innovation using primary literature. The components of this semester-long course provided the interdisciplinary student audience with a working knowledge of biotechnology and bioengineering, while helping them appreciate the complementary aspects of their diverse educational backgrounds. The framework, implementation, and results of the course are presented in this work.

INTRODUCTION

THIS PAPER describes the development and successful implementation of a unique graduate bioengineering and bioengineering course open to advanced undergraduates at UNC Charlotte. The course was designed to simultaneously introduce engineering, biology, physics, and chemistry students to biotechnology and bioengineering. Biotechnology and bioengineering can be broadly defined as the development of technologies or devices that improve the environment or quality of life. The biotechnology and bioengineering topics covered in this course were chosen because each exemplifies how the line between biotechnology and bioengineering can often be indistinct. In the current climate where cross-disciplinary training is desired [1, 2], the structure of this course demonstrates some of the instructional variations that can be employed when developing interdisciplinary coursework. Courses such as this that encourage engineering, biology, chemistry and physics students to learn from each other and discover their complementary talents, can serve as a forum for cross-disciplinary communication.

Cooperation between basic scientists and engineers in technological development is essential and mutually beneficial. Advances in biomedicine, bioinformatics, biomaterials, and bioremediation are transforming the face of biotechnology [1, 3]. The next generation of biotechnological advancements will continue to require interdisciplinary communication among engineers, biologists, and physical scientists. Likewise, in all aspects of bioengineering, biology helps provide the framework for understanding which questions and problems are important, while the engineering is critical to developing effective solutions. Hence the cross-disciplinary exposure gained by engineers and biologists working in interdisciplinary teams, will have an impact beyond the development of immediate applications [1]. Yet one limitation in developing effective working groups of basic scientists and engineers is that professionals often lack the common vocabulary and cross-disciplinary exposure needed to effectively engage in interdisciplinary communication [1].

Early participation in interdisciplinary activities by engineering, biology, and physical science students could begin at the undergraduate level. However, the highly structured engineering undergraduate curricula at most universities can discourage engineering students from enrolling in biology course work. Another obstacle for students interested in interdisciplinary training is that most science and engineering classes require prerequisites that are not easily satisfied by nonmajors.

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At UNC Charlotte there is a growing impetus for students to gain exposure to the cross-disciplinary nature of biotechnology and bioengineering. For instance, graduate students within the University's traditional engineering graduate programs (e.g., mechanical engineering, electrical engineering, etc.) working on projects with potential biomedical applications, need a forum for learning key biological concepts. Similarly, a newly developed interdisciplinary doctoral program in Biology required that its students gain an understanding of problem solving approaches in biotechnology and bioengineering. Finally, engineering undergraduates interested in pursuing bioengineering in graduate school require an introduction to bioengineering. In the absence of a formal bioengineering undergraduate or graduate program at UNC Charlotte, new coursework was developed to fulfill these needs.

THE FRAMEWORK

The formal course prerequisites for 'Biotechnology and Bioengineering' were introductory physics and inorganic chemistry since they are common to the curricula of the engineering, biology, and physical science target audience. Graduate standing, or at minimum advanced undergraduate standing, were requirements since the course's framework was structured on the understanding that its students were already reasonably proficient in their respective undergraduate disciplines. Maximum enrollment was set at 16 students for the inaugural offering of this 16-week course to maximize discussion and interaction.

Goals of the course

The primary goals of the course were to provide students with basic principles in biology and engineering, give them a working knowledge of biotechnology and bioengineering applications, and establish a climate for engineers, biologists, physicists and chemists to learn from each other. The specific learning objectives and instructional format of the novel Biotechnology and Bioengineering course were designed to achieve these course goals.

Instructional objectives

The Biotechnology and Bioengineering course was designed to accomplish several learning objectives that were continually assessed throughout the semester. As shown in Table 1, the five learning objectives were assessed using the fairly traditional methods (i.e., examination, homework, quizzes, and projects), in combination with cooperative learning exercises. Details of the cooperative learning exercises and the final projects are given in the Implementation Strategy section below.

Instructional format

The Biotechnology and Bioengineering Course was developed and taught by a faculty team consisting of a biology professor and a mechanical engineering (MEGR) professor. Consequently, the course linked engineering with biology in its course content and its instruction. Furthermore, both faculty members were present at each lecture. This ensured continuity of the lectures, and also enabled the students to pose questions to either instructor in accordance with the professor's expertise. The presence of both professors at every lecture had the added benefit of ensuring that the course material was presented clearly and effectively (i.e. devoid of jargon) for a varied audience. On several occasions, the engineering and biology content of a topic was presented within a single lecture period.

The 16-week course consisted of two class meetings per week of 80 min duration. To complement lectures on the fundamental science and engineering of a topic, applications lectures were presented throughout the semester. Research specialists from the University, Carolinas Medical Center, and the Whitaker Foundation, supplemented application lectures given by the course's instructors with guest lectures. These served to expose the students to current research developments. In addition, a course web site developed and maintained by the

Table 1. Learning objectives and their methods of assessment

Learning Objectives	Assessment Method
1. Understand key science and engineering principles that are fundamental to biotechnology and bioengineering.	a. Cooperative Learning Exercises b. Homework and Quizzes c. Exams
2. Advance from the *understanding* of these key principles (Learning Objective #1) to their *application* in current Biotechnology and Bioengineering innovations.	a. Exams b. Homework c. Final Projects
3. Communicate effectively—through written and oral communication—with a cross disciplinary audience.	a. Exams b. Cooperative Learning Exercises c. Final Projects
4. Effectively participate in interdisciplinary teams.	a. Cooperative learning Exercises b. Homework c. Final Projects
5. Critically analyze biotechnology/bioengineering innovations for the need that it meets and its overall technical or social impact.	a. Exams b. Final Projects

professors, served as a resource for the students. From this URL the students could review the syllabus, overviews of each lecture, homework assignments, and any class announcements. Note also that there was no required textbook for this course. Instead, the two suggested textbooks were *The Way Life Works* by Hoagland and Dodson [4] and *Introduction to Biomedical Equipment and Technology* by Carr and Brown [5].

IMPLEMENTATION STRATEGY

The first offering of the new Biotechnology and Bioengineering course occurred during the Spring 1998 semester. The enrollment and composition of the course is presented in Table 2. As shown, the class consisted of 8 biology students and 8 non-biology students; and the graduate to undergraduate (i.e., seniors) ratio was also 1:1. Another important point is that 75% of the graduate student population consisted of biology students, while 75% of the undergraduate population consisted of non-biology students. For an interdisciplinary class of this type, the class distribution during any given semester is important since the rate and detail in which the professors can cover course material is influenced by the capabilities of the student population. Because a higher percentage of the biology population were graduate students, care had to be taken to ensure that the course content challenged each student. For this reason, the lectures were structured to present their biological content from an engineering point of view, rather than using the traditional biology model. Furthermore, since the calculus training of engineers and physicists varied greatly from that of biologists and chemists, the engineering content also had to presented in a way that educated the non-engineers, yet challenged the engineers to apply their technical knowledge to new and unfamiliar applications. The lectures and assignments of the Biotechnology and Bioengineering Course were formulated with these intentions.

Table 2. Class composition

Spring 1998 Enrollment	Number of Students
Undergraduate Students	
Engineering	4
Mechanical Engineering (3)	
Electrical Engineering (1)	
Biology	2
Physics	1
Chemistry	1
Master of Science Graduate Students	
Engineering	2
Mechanical Engineering (1)	
Electrical Engineering (1)	
Biology	6
Total	**16**

Lecture topics

Each class period consisted of a lecture on a single topic given by one of the instructors or an invited guest, a cooperative learning exercise, and/or student discussions on a question arising from either a lecture topic or the homework. Figure 1 gives an overview of the topics and applications discussed over the course of the semester. As shown, the five topic areas ranged from 'Engineering and Biology of Motion' to 'Immune Response to Engineered Devices', and were selected because each blurs the line between the fields of biotechnology and bioengineering. Each topic provided a context for teaching the engineering and biology fundamentals as a foundation for later discussions of the applications and innovations. They also provided an avenue for presenting biological material from the engineering perspective. The topic choices also served to challenge the students to consider the interconnectedness and interdependency of all branches of engineering and science in the development of new biotechnology and bioengineering innovations.

As shown in Fig. 1, the course topics are based on biology, hence they are easily recognized by biology students. Yet recent developments in each of these five areas were made possible by engineering breakthroughs. Hence, to simultaneously accommodate the course's cross-disciplinary audience, each topic was first presented from an engineering viewpoint. For example, although 'Engineering and Biology of Motion' (refer to Fig. 1, Topic 1) conjures up images of skeleton, muscles and nerves—the first lecture on this topic discussed the body as a mechanical design. The biological aspects of the topic were then tailored to continue the design discussion from the gross level (e.g. skeletal design for load, optimal muscle design for action etc.) to the cellular level (e.g. the role of cell function in bone remodeling, etc.). Use of the engineering design approach for this topic also allowed us to present biological and engineering fundamentals such as energy metabolism, thermodynamics, cell design and function to the class, while challenging the biologists to rethink their view of basic concepts.

Topic 2, 'Bioremediation in Environmental Engineering', was presented using an engineering format that introduced micro-organisms and bacterial function in diverse environments to the engineers, and exposed the biologists to biotechnology from an environmental engineering perspective. Likewise Topic 3, 'Genetic Engineering', was taught from the standpoint of improving graft designs, which made it interesting to the non-biologists and forced the biologists to consider genetic engineering in the context of device design.

The final topics for the course, 'The Cardiovascular System' and 'Immune Response to Engineered Devices', respectively, were introduced from the standpoint of developing elegant design (e.g. how to make better heart valves) and problem solving (e.g. how to keep the body from interfering

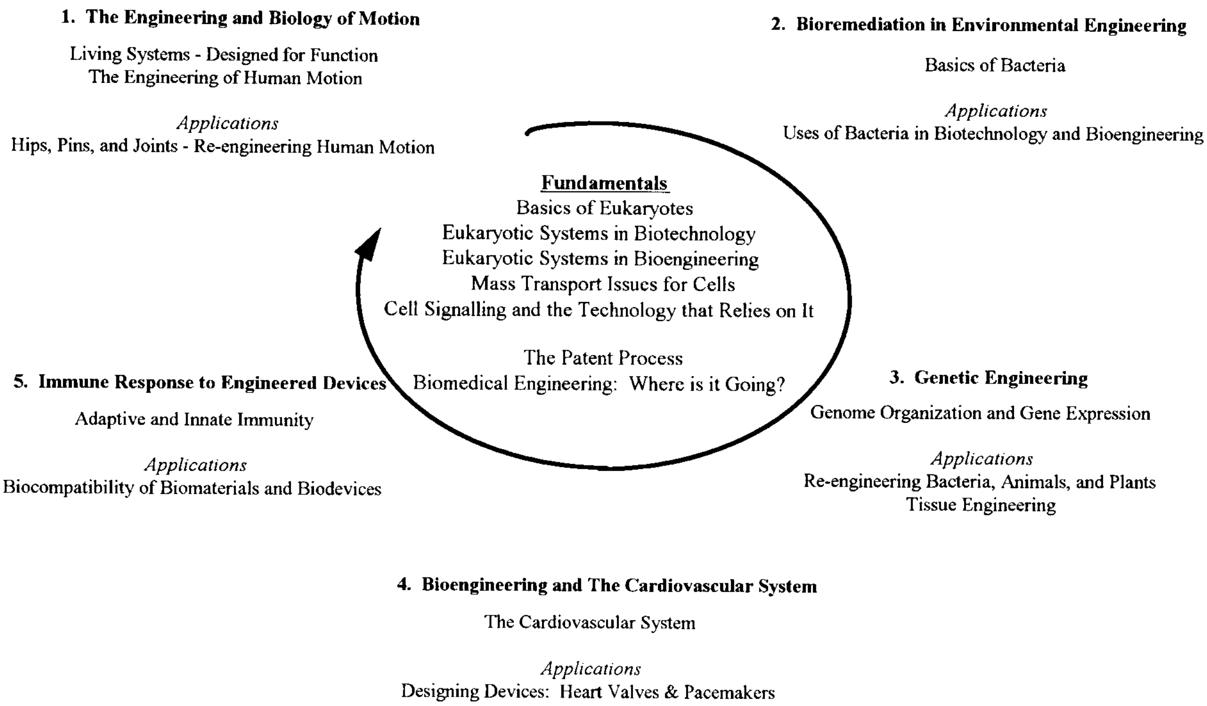

Figure 1. Schematic of course topics.

with the function of implanted devices). Discussion then extended to the complex topics of cardiovascular biology and whole-body immune response. These broader topics allowed the students to appreciate that the development of technology is of immediate concern in biotechnology and bioengineering, yet the practitioner must also consider its application for the technology to become part of a complex living system such as the human body.

Guest speakers

A limited number of guest speakers were utilized throughout the semester to enrich the learning experience for the students. Totaling six lecture periods, these invited lectures helped the students grasp the direct applications of the fundamental science and engineering principles. One notable exception was the capstone lecture entitled: 'Biomedical engineering: where is it going?' (refer to Fig. 1) delivered by Dr Peter Katona, Executive Vice-president of the Whitaker Foundation of Rosslyn, VA. Dr Katona's seminar, delivered at the end of the semester, served to give the students a global understanding of the biomedical engineering field and its potential.

Interdisciplinary teamwork

One of the learning objectives (Table 1) was for the students to learn to participate effectively in interdisciplinary teams. Consequently, it was critical that the structure of the course promoted team interactions throughout the semester. While a variety of techniques exist to facilitate group interactions [6, 7, 8], the importance of practicing the techniques under controlled conditions, employing accountability measures, and iteratively improving the exercises has been established in the literature [9]. Active cross-disciplinary group interactions were incorporated into 'Biotechnology and Bioengineering' using in-class cooperative learning exercises and final team projects. Each is discussed in detail below.

Cooperative learning

To facilitate interdisciplinary communication, two cooperative learning exercises were devised during the semester. Smith and co-workers define cooperative learning as the use of small groups of students working together to maximize their own and each other's learning [7, 9]. For each cooperative learning exercise of the Biotechnology and Bioengineering Course, the class was divided into four teams consisting of four students per team. The preferred discipline distribution was one engineer and one biologist per group, since one of the exercises incorporated engineering concepts not explicitly covered in lecture, while the other exercise had a biology bias. Yet to accommodate the student distribution shown in Table 2, the criteria used for the group assignation was that the number of biology students in any group could not exceed two. The four-person group size ensured accountability, since each team member had to accept the role of *facilitator* (ensures that all team members participate in the discussion); *recorder* (writes down group answers for each question so it can be turned in as the group submission); *fact-checker* (verifies group's problem-solving strategy using lecture notes and

Table 3. Final projects of the Biotechnology and Bioengineering Course

Team Project Title	Team Composition
Microwave Tomography	Electrical Engineering undergraduate student and Physics student
Sheep Cloned by Nuclear Transfer Technology Bearing a Human Gene	Mechanical Engineering undergraduate and Biology undergraduate
Development of the St. Jude Medical Prosthetic Heart Valve	Mechanical Engineering undergraduate and Biology graduate student
An Adjuvant to Radiotherapy and Cancer Treatment: Hyperthermia	Biology graduate student and Mechanical Engineering undergraduate student
Probe Membrane Mapping of Microvascular Networks	Biology graduate student and Mechanical Engineering graduate student
Biodegradable Plastics Made By Recombinant DNA Technology	2 Biology graduate students
Lab-on-a-Chip	Chemistry undergraduate student and Biology undergraduate student
Medical Ultrasonics: Theory and Applications	Electrical Engineering graduate student and Biology graduate student

textbook); and either *calculator* (calculates numerical answers) or *a responder* (orally reports and defends group results to the class for each team exercise) [7, 9]. These cooperative learning exercises were effective mechanisms for reinforcing, synthesizing, and applying the lecture material. They also helped the students begin to practice and understand the value of learning from each other. For this course, the team composition changed with each cooperative learning exercise.

Final projects and presentations

In addition to the in-class team exercises, each student was required to work with a classmate to critically evaluate a current biotechnology and bioengineering innovation. Students were strongly encouraged to partner with a person of a different discipline in order to prepare a 10-page written report and a 15-min oral presentation of the biotechnology or bioengineering application of their choosing. The written and oral requirements of the project were important for developing the students' capabilities in presenting and defending technical information to a cross-disciplinary audience. This assignment also helped each student build proficiency in working in cross-disciplinary teams and in communicating effectively with colleagues trained differently than themselves. To ensure active participation, the members of each two-person team received the same grade as their collaborator for each aspect of the assignment. A list of the project titles and the composition of each team are depicted in Table 3. As shown, 7 of the 8 projects were completed by cross-disciplinary teams, and the projects ranged from nanotechnology to medical ultrasonics. The written projects were graded by each of the course instructors, while the instructors and the students of the course evaluated the oral presentations. Peer evaluation of each team was completed with the aid of written evaluation forms. Anonymous peer review comments were provided to the presenters as immediate feedback on how each presentation was received by the student audience.

As a consequence of the formal team assignments (e.g. cooperative learning exercises and final projects), it was observed that the student participation in interdisciplinary study groups outside of class also increased throughout the semester. Study group activities were typically initiated for the purpose of discussing the application lectures, completing homework, or preparing for course exams.

STUDENT ACTIVITIES AND EVALUATION

Each student's final course grade was earned based on 5 key criteria—three exams (20% each), homework and quizzes (10%), class participation (10%), the written final report (12%) and the oral presentation (8%). The examinations consisted of two in-class examinations covering modules of the course material, and a third comprehensive final examination. These exams were structured to test the student's understanding of relevant biology and engineering fundamentals, and their ability to use the fundamental knowledge to critically analyze applications. The latter was achieved by posing questions that required the students to synthesize course topics and critically analyze the limitations and shortcomings of current biotechnology and bioengineering designs. The homework assignments and quizzes of the course were designed to promote out-of-class discussions and prepare students for the examinations. Class participation received its weighting to promote in-class questions and participation in class discussions. Student performance on the oral and written segments of the final team project grade was evaluated as previously described. Both course instructors graded all student papers.

Final course grades were based on a 10-point scale. Interestingly, students in this demanding course performed well, as indicated by the grades of A or B earned by each of the students (refer to Table 4). Although graduate students in biology earned the largest percentage of the A's,

Table 4. Student final grade distribution by program and discipline

Biology				Physical Sciences				Engineering			
Undergraduate		*Graduate*		*Undergraduate*		*Graduate*		*Undergraduate*		*Graduate*	
A	B	A	B	A	B	A	B	A	B	A	B
1	1	5	1		1			2	2	1	1

Note: There was 1 physical science undergraduate student audit

the distribution of A and B grades among undergraduates in engineering, biology, the physical sciences was comparable.

STUDENT FEEDBACK

Throughout the Biotechnology and Bioengineering Course, students were presented with three formal opportunities to evaluate the course and provide feedback to the faculty. The first opportunity for written student feedback occurred at Week 4 of the course, where students were asked to anonymously evaluate faculty performance, course topics, course format, and the interdisciplinary interactions of the course by responding to an informal questionnaire. During week 15 and 14 of the course, 2 independent end-of-the-semester course evaluations were conducted using standardized evaluation forms used by the College of Arts and Sciences and the College of Engineering. Students were asked to respond to standardized questions assessing all aspects of the course. In addition, students were encouraged to discuss strengths and weaknesses of the course. To ensure student confidentiality, all evaluations were completed without instructor supervision, and the offices of the Biology and Mechanical Engineering departments compiled the results. Student feedback was shared with the faculty as a typed list following submission of final grades.

The student feedback results indicate that the Biotechnology and Bioengineering Course was well received by the students in the engineering, biology, chemistry, and physics students of the course. Because each evaluation form was administered to all students present in the class on the day of evaluation, the College of Art and Sciences and the College of Engineering results reflect the responses of the overall student cross-section, irrespective of the student's departmental affiliation. *All* students agreed or strongly agreed that the course: was stimulating and presented in an effective style; used good examples and emphasized the relationship between topics; stimulated thinking and challenged the students to learn; and covered a reasonable amount of material. Student responses to the three summary questions on the end-of-semester evaluations are provided in Table 4. Scored on a scale of 1 (strongly disagree) to 5 (strongly agree), 85% of the respondents agreed or strongly agreed with each of the summary statements listed in Table 5. A breakdown of individual student responses to these summary questions (data not shown) indicated that two students either disagreed or strongly disagreed with the summary statements. The reasons for their dissatisfaction could not be discerned from this confidential evaluation process or from student contact during the semester.

Representative student written comments

In their written comments, students were invited to discuss the course's strengths and weaknesses and provide suggestions for its improvement. As seen below, the majority of the students spoke to the team-taught nature of the course, the cooperative learning exercises, and the bioengineering application lectures delivered by the guest speakers. Although the student comments below were generally positive, their responses also point to aspects of the course that should be iteratively improved. One of these, the students' interest in expanding the coverage of more traditional engineering topics, is discussed in the next section.

- 'Interesting aspect of the course is this dual instructor system. Very useful in giving two points of view both biological and bioengineering. Effective when questions came up that one instructor can answer better than the other. Good way of teaching this course. The group work was effective in getting other classmates' viewpoints on similar subjects. Especially useful when going over engineering or biological topics and being able to ask group members who have expertise in particular area. Guest speakers were always very informative and definitely interesting.'
- 'Cooperative learning between classmates was essential in seeing how other fields view similar problems. It was a benefit to combine backgrounds. Guest speakers: a good benefit showing diverse applications.'
- 'The team-taught nature of the course was very effective; having a biologist and engineer in the class allowed us to have questions answered by experts in the field; team work was good in the class, as an engineer, I had the opportunity to work with biologists for the first time and I learned a lot from the experience; guest speakers gave me the chance to see some of the real-world applications of what we discuss in class.'
- '[Professors] did a good job teaching together; both attended classes and were accessible during class. I've been in a class that 3 professors taught and it was difficult because they each approached it differently. I didn't experience this

Table 5. Summary questions from student evaluations

Question	College of Arts and Science			College of Engineering		
	Course Mean ± SD	*Dept. Mean ± SD*	*College Mean ± SD*	*Course Mean ± SD*	*Dept. Mean ± SD*	*College Mean ± SD*
1. Overall, compared to other courses, I have learned a great deal in this class	4.38 ± 0.77	4.11 ± 0.98	4.11 ± 0.98	ND	ND	ND
2. Overall, this course is among the best I have ever taken	4.15 ± 1.28	3.67 ± 1.18	3.49 ± 1.23	3.79 ± 1.19	3.55 ± 1.27	3.33 ± 1.27
3. Overall, this (these) instructor(s) is (are) among the best teachers I have known	4.46 ± 0.78	3.97 ± 1.11	3.79 ± 1.19	4.15 ± 1.07	3.82 ± 1.32	3.62 ± 1.28

(5 = strongly agree and 1 = strongly disagree)
SD: standard deviation; ND: not determined
Course Mean ± SD: Mean score and SD of all student responses evaluating the biotechnology and bioengineering course
Dept. Mean ± SD: Mean score and SD of all biology lecture courses evaluated by students
College Mean ± SD: Mean score and SD received by all College of Arts and Sciences or all College of Engineering courses evaluate by students

problem with Dr Coger and Dr de Silva. Atmosphere was technical but tended toward biology, but I think that was needed because the applications were biology based.'

- 'The way the course was taught by 2 professors from biology and MEGR was effective. It allowed questions to be answered by who ever was the expert in the field. The class also gave me the opportunity to get to know some of the biology students and professors. It greatly expanded my knowledge of biology of the bioengineering applications of my MEGR education. Guest speakers were also interesting. They gave me an idea of what kind of opportunities are available after graduate school.'
- 'Some of the topics in engineering were superficial and being a biologist I was confused. I think we have to go into more details so that we get a thorough understanding of the concepts.'

CONCLUSIONS

The Biotechnology and Bioengineering Graduate Course was developed to introduce the fundamentals and applications of these fields to engineering, biology, and physical science students. One expectation was that the students would obtain sufficient knowledge of biotechnology and bioengineering to engage in cross-disciplinary teamwork. A major challenge in developing a course that addressed the needs of this cross-disciplinary group, was in making the course free-standing such that no prerequisites beyond the basic physics and inorganic chemistry courses common to the engineering, physical science and biology curricula were required. Yet, training students to work in cross-disciplinary teams also meant teaching basic biology principles to engineers and physical scientists, *while* training biologists to consider biological processes and systems from the perspective of mechanics, mass transport, and design principles. Thus it was necessary to achieve a balance between the breath and depth of topics covered in this challenging course. We sought to accomplish this by limiting the topics discussed to five major areas (Fig. 1). This also served to challenge the students to consider the interconnectedness and interdependency of all sciences in the development of new innovations.

A challenge encountered by the instructors was in finding an appropriate textbook for the class. Although both of the course's suggested texts were well written, neither book was appropriate to the goals of the Biotechnology and Bioengineering Course. For instance, *The Way Life Works* by Mahlon Hoagland and Bert Dodson [4] was helpful in relating biology concepts to everyday life, however, providing a bioengineering framework was not an intention of this publication. Similarly, Carr and Brown's *Introduction to Biomedical Equipment and Technology* [5] was helpful for specific topics, yet it generally focused on electrical engineering applications. Consequently, it was not designed to present a range of biotechnology and bioengineering applications to a cross-disciplinary audience. In the absence of a suitable course textbook, the students had to rely chiefly on the information presented within the lectures. To ensure that these textbook limitations were not obstacles to the successful execution of the course, careful and thorough preparation of the course material was necessary. For this reason, the two-faculty team made a year-long time investment in developing the new Biotechnology and Bioengineering Course.

Implementing the Biotechnology and Bioengineering Course revealed two elements requiring special attention. First, biological jargon must be used as sparingly as possible during the lectures.

This is necessary to facilitate student understanding of the fundamental biological concepts, without overwhelming engineering and physical science students with new terminology. In teaching the course it also became evident that the homework and in-class exercises addressing engineering problem solving were significantly constrained by the biology and chemistry students' limited exposure to calculus. The consequences of this were noticed by the students (refer to the sixth student comment of the previous section). In future iterations of the class, engineering analysis exercises will be introduced earlier in the course. Also, to further increase the extent of problems that the students are able to solve, conceptual analogies (i.e. electrical circuitry) will be used when feasible, to describe biological processes [10]. In this way, students will gain experience in reducing the complexity of biological systems to their mass and energy transport equivalents. This will also help the biologists and the chemists of the course to gain confidence in analyzing systems using engineering approaches. This teaching method is also expected to aid the students in proposing ways to improve biological systems by considering the functions of the original system.

The student performance and the student feedback results suggest that the Biotechnology and Bioengineering Course was successful in achieving its learning objectives (Table 1). Key elements to the success of the course were:

- the dynamics and commitment of the course's instructors;
- the implementation of interdisciplinary student teams early in the semester;
- the inclusion of carefully selected guest lectures on specific biotechnology and bioengineering applications.

The successful implementation of this unique course demonstrates that bioengineering instruction can be accomplished in the absence of a formal bioengineering program, through the collaboration of faculty from engineering and basic science disciplines. The novel approach to curriculum development described here, relied on dynamic cross-disciplinary interactions between the faculty and the students. The use of fundamental and application lectures, and team assignments (e.g. cooperative learning exercises and the final projects) helped the students gain a real understanding of the interdependence of engineering, biology, physics and chemistry in the fields of bioengineering and biotechnology. This introductory graduate course is expected to provide students with a strong basis for future research, and influence the way they approach thinking within their individual disciplines.

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