AC 2011-425: AN INVESTIGATION OF BIOENGINEERING UNDERGRADUATE CURRICULUM: METHODS FOR A COMPREHENSIVE ANALYSIS

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An Investigation of Bioengineering Undergraduate Curriculum: Methods for a Comprehensive Analysis

Abstract

The field of bioengineering is dynamic and constantly evolving. As such, its undergraduate programs must also evolve and adapt, in order to provide students with the knowledge and skills necessary to embark on successful careers and to contribute to the advancement of the current state of bioengineering. To this end, at our institution we have conducted an extensive examination of our undergraduate bioengineering program. The goal of this study was to utilize a variety of assessment techniques in order to enhance our understanding of the strengths and limitations of our curriculum and to identify any aspects of the curriculum which could be optimized to better meet the needs of the modern bioengineering undergraduate student.

In this paper, we present our comprehensive approach to assessing the effectiveness of the current curriculum at the University of Washington. We describe the multiple methods of self-analysis implemented over the course of our study, including acquisition and evaluation of feedback from departmental faculty, academic staff, industry, student alumni, and students enrolled in the program. In addition to describing formative feedback techniques and their findings, we also discuss how results from those assessments were directly translated into curriculum revision actions by our department.

Preliminary effectiveness of the proposed changes in the bioengineering curriculum was assessed through survey responses from industry, non-University of Washington academic colleagues, student alumni, and current students. These results indicate that our integration of feedback obtained from the multiple means of assessment allows for critical analysis and well-informed revision of the curriculum. We are encouraged by the high level of satisfaction regarding our new curriculum displayed by numerous constituents. Although future assessment of the success of curriculum changes will be needed as the new courses are phased in (January 2011), we propose that the methods of program analysis described in this work may be useful for other departments similarly motivated to evaluate their own curriculum.

Introduction

The goal of the undergraduate Bioengineering (BIOEN) Program at the University of Washington (UW) is to prepare students for entry into graduate school, professional school (i.e. medical, dental, law), or industry. To ensure that our undergraduate curriculum aligns optimally with this goal, we have conducted an extensive examination of our undergraduate bioengineering program. Here, we present methods used to evaluate our program from a variety of perspectives, relevant to the variety of post-undergraduate endeavors pursued by our students. In an effort to undergo a complete evaluation, we sought to obtain formative feedback from a variety of methods, including faculty/staff curriculum meetings, student alumni surveys, and interviews with current students.

For example, one method of program evaluation consisted of annual undergraduate program feedback sessions. During separate feedback sessions conducted with both junior and senior undergraduates, students completed individual worksheets and then met in small groups to discuss and record responses to particular questions regarding undergraduate program issues, such as departmental strengths and recommended changes to the curriculum. After the small group sessions, students discussed their responses as a large group and proceedings were later summarized by the facilitator. As one portion of the study presented here, anonymous student feedback obtained from sessions from the past eight years (2003 – 2010) was analyzed. The results allowed us to gain insight into the strengths and challenges of our program from the perspective of the students and clearly identified potential areas for optimizing their educational experience. For instance, although seniors indicated that they were overall well-satisfied with the bioengineering program (3.8 ± 0.4, on a 5 point scale), 71% of the group session reports cited the desire for track-based elective options based on a thrust area, in order to increase the specificity of their knowledge. The desire for specialized track-based elective options was recapitulated in student alumni surveys as well. Based on this feedback, we plan to implement a requirement for focus area specialization in the new curriculum.

Based on both the quality of students admitted and graduated and on the placement of our graduates in top graduate schools, medical schools, and local industry, we were already providing a strong and successful program. Nonetheless, the ongoing assessment methods described in this paper identified recurring issues not readily addressed by course-level changes. Hence, consideration of the results from these approaches led to an entire revision of the undergraduate BIOEN curriculum by UW faculty and staff. Subsequent feedback from industry, non-UW academic colleagues, student alumni, and current students serves as a method to assess the levels of satisfaction regarding our new curriculum plan from the perspectives of our constituents, as well as to identify any potential refinements needed.

Student Alumni

We considered obtaining feedback from student alumni to be extremely important in the effort to make informed decisions about changes needed in the undergraduate curriculum. Alumni have had a chance to reflect upon and utilize their BIOEN education in an outside forum and can therefore provide a useful perspective for shaping the curriculum. Many of the skills we attempt to develop in our undergraduates may not be appreciated by students until they have become immersed in their post-graduation career and have had the opportunity to apply their knowledge.

Methods

Student alumni email addresses were obtained through the UW Advancement Office. Web-based surveys were then sent out to graduates from 2003, 2004, and 2005, and anonymous responses were submitted by a total of 17/43 student alumni (39% response rate). This survey was sent out in 2006 and was originally designed to enable our department to assess competency in ABET outcome (i) a recognition of the need for, and an ability to engage in life-long learning[1] by gathering data on continued training, conference attendance, etc., but alumni were also asked about the level of preparation for future positions provided by the undergraduate BIOEN program. Survey results were analyzed to identify any reoccurring themes in alumni feedback.

Results

Quotations from Student Alumni	Summary Points: What Changes Are Advised?
• "An engineering degree should prepare students to attain a position in industry immediately after graduation. As the curriculum was structured [in 2004], the bioengineering degree fell short of this objective." • "I am extremely happy with the education I received. I believe I have more research experience and more comprehensive knowledge than [graduate school colleagues]." • "I felt that the organization of the curriculum had much room for improvement at the time I was a student." • "I felt that the BIOEN curriculum provided a very strong foundation for a student entering medical school or a PhD program. As far as preparation for industry, I would have been very reluctant to attempt going for a specialized job after the curriculum." • "Familiarity with MATLAB was [a] valuable skill." • "Junior class hit [learning] targets much more than senior ones." • "I feel that I have unique training in the biomedicine field. There are very few people who can sit down and figure out a problem using logic in the first year of graduate school. I feel that the "non-book-smarts" that the BIOEN program has given me has allowed me to succeed now."	• Increased preparation for industry. • Overall organization of courses within the curriculum. • More rigorous, specialized senior electives (focus area). • More integration of MATLAB in curriculum. • Increased emphasis on engineering skills (MATLAB, controls) • Professional skills (teamwork and communication skills) well-addressed by program; no changes needed. (5.4/6 average rating for how well the BIOEN undergrad degree prepared alumni for the ability to work in multidisciplinary teams and communicate problems and their solutions effectively)

Table 1. Representative quotations submitted by student alumni regarding their perceptions of their preparation received in our BIOEN program.

This student alumni survey provided qualitative results (Table 1) which were instrumental in identifying aspects of the curriculum which required attention. Many of the concerns cited by student alumni were recapitulated in feedback sessions conducted with current students, described below.

Current Junior and Senior BIOEN Undergraduates

Besides surveying student alumni, an additional program evaluation consisted of annual undergraduate program feedback sessions facilitated by staff from the UW Center for Instructional Development and Research. We submit that the approach of utilizing an outside party to conduct the feedback sessions allows our department to obtain information more rigorously, because students are able to answer honestly without any perceived pressure from current professors or mentors. The results of this analysis allowed us to gain insight into the strengths and challenges of our program from the perspective of the students and clearly identified potential areas for optimizing their educational experience.

Methods

During separate feedback sessions conducted with both junior and senior undergraduates, students first completed individual worksheets and then met in small groups to discuss and record responses to particular questions regarding undergraduate program issues. [Questions posed on the worksheets relevant to this work included: What is your overall level of satisfaction with the BIOEN major? What is your confidence in the quality of preparation for your next step after graduation? What are the strengths of the program? What changes would you recommend in the program, and how would you recommend those changes be made?] After the small group sessions, students (n = 6 – 37, dependent on the year since cohort size has increased over time) also discussed their responses as a large group and proceedings were later summarized by the facilitator and anonymous responses were presented to our department. Student feedback obtained from sessions from the past eight years (2003 – 2010) was analyzed. Quantitative feedback was obtained from years 2005 – 2010.

Results

Seniors indicated that they were overall well-satisfied with the bioengineering program (3.8 ± 0.4, on a 5 point scale). However, 71% of the group session reports cited the desire for track-based elective options based on a focus area, in order to increase specificity of their knowledge. Considering this finding along with the student alumni survey results, we now plan to implement a requirement for focus area specialization (i.e. Diagnostics and Instrumentation, Molecular Bioengineering, Biomaterials/Tissue Engineering/Medical Devices, Cellular and Systems Bioengineering) in the new bioengineering undergraduate curriculum.

Recurring suggestions from the seniors also included adding a mass transport class to the undergraduate curriculum and replacing a required Java-based Computer Science and Engineering (CSE) course with a MATLAB-specific course, citing MATLAB's relevance to both research and industry.

The new curriculum has a substantially revised BIOEN core that includes two transport courses, which are needed to cover topics such as thermodynamics, fluid mechanics, reaction kinetics, and momentum transport. This is also in line with practices in other bioengineering departments, where biotransport and thermodynamics are addressed in the core curriculum of all six departments we surveyed (for example, one semester for each topic for Rice University and MIT). Java programming has been replaced by an applied math course that teaches MATLAB and numerical analysis techniques (Appendix A and B).

We also conducted a comparison of how prepared seniors felt for their intended next steps after graduation. Although there is expectedly variation from year to year, the data appear to echo the sentiment conveyed by student alumni regarding the strength of our department in preparing students for professional and graduate school but the need to increase preparation for entry into industry (Figure 1). In an effort to address this concern even further, we have sought and obtained feedback from industry professionals regarding the knowledge and skills they value in a recently graduated bioengineer (presented subsequently).

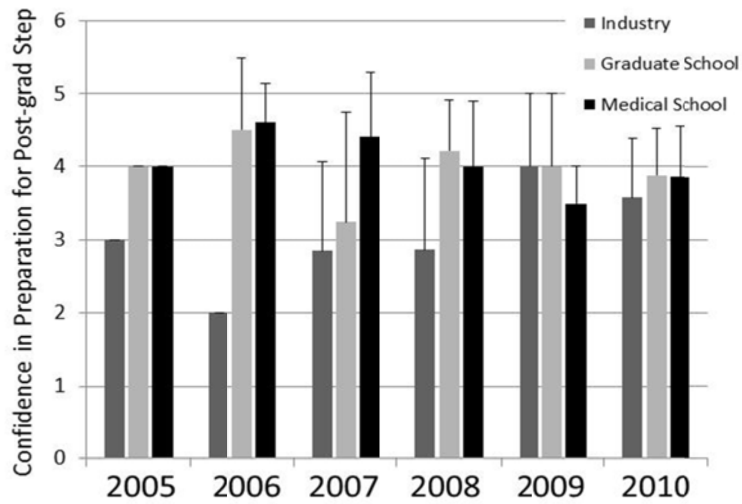

Figure 1. Ratings submitted by BIOEN seniors regarding their confidence in their preparation for post-graduation plans (5 = very highly confident, 0 = not at all confident). Data are displayed as mean + standard deviation.

Recurring themes in the recommendations from juniors included suggestions to add a mass transport course and to reexamine the program's prerequisites, citing that too many prerequisite courses are taken outside the BIOEN department. Lastly, juniors presented the desire to have an increased quantitative basis in their physiology course.

Intradepartmental Proceedings: New Curriculum Development

Having successfully navigated the ABET accreditation process in 2008, the department determined it had enough experience and formative feedback to undergo an examination of the curriculum. Consideration of the results presented above ultimately led to an initiation of curriculum revision by the BIOEN faculty and academic affairs staff. The first step consisted of a "Curriculum Summit," in which faculty and academic affairs staff met at length to discuss previously-assigned topics, including core course sequencing and content, program requirements, and the Capstone Senior Design experience. Student representatives also attended the Curriculum Summit and were asked to research students' opinions regarding Summit conclusions.

The Curriculum Summit identified many issues in the curriculum including: 1) the need for more rigorous senior electives, 2) the presence of gaps and redundancies among BIOEN core courses, 3) the need to align with faculty expertise/strengths, and 4) the need for more math content, transport phenomena, and molecular bioengineering, which were subsequently discussed through Curriculum Committee meetings with core course instructors and undergraduate student representatives during the 2008-2009 academic year. During extensive sub-committee meetings in summer of 2009, specific revisions to the curriculum were proposed and presented at BIOEN faculty meetings. In June 2010, final central approval was obtained for the new BIOEN undergraduate curriculum (Appendix A and B). Building upon the extensive research conducted by the VaNTH Engineering Research Center, our curriculum plan incorporates recommended topics and content for undergraduate bioengineers, including calculus, linear algebra, ordinary differential equations, high level computer language (i.e. MATLAB, chemistry, physics, and genetics, molecular biology, and cell biology[2].

In the new curriculum, physiology concepts are introduced first through biology courses which address genetics, cell biology, sensory and circulatory systems, gas exchange, chemical controls, and motor and nervous systems. Physiology content is also incorporated throughout the BIOEN core. For example, the Biomedical Signals and Sensors course will address the sources of neuromuscular signals, and biotransport concepts will be discussed in the context of blood oxygenation, renal processes and urinary dialysis. In the core Biomolecular Engineering course, students will learn biomolecular structure and function. The physiology course in the BIOEN core, Failure Analysis of Human Physiology, involves the application of engineering analysis to the understanding human physiology and pathology and the engineering of solutions to medical and biological problems. This course will address the physiology and failure of cardiovascular, cancer, and immunological systems. Topics in vascular biology include flow, hemostasis, inflammation and atherosclerosis, cardiac mechanics and electrophysiology, and angiogenesis. Cancer biology topics include tumorigenesis, tumor physiology, and maintenance of genomic integrity. Immunological systems and failures will include topics on immune cells and the effector mechanisms that orchestrate an immune response to pathogens, foreign body response related to transplantation, immunity in cancer, and diseases caused by immune responses.

An additional change in the curriculum that deserves discussion is the removal of the third physics course (Waves) requirement. A solid foundation in physics principles is provided by the two required physics courses, Mechanics and Electromagnetism, so students have all the necessary material to proceed through the BIOEN core. Instead of requiring *all* students to take a third physics course which is more relevant to an imaging specialization, students interested in pursuing an instrumentation or imaging focus are advised to take Waves.

One key aspect of the curriculum revision is that the undergraduate BIOEN program is now more aligned with the strengths and expertise of the faculty, which is a recommended principle when building a new BIOEN curriculum[3]. In particular, the general shift from an instrumentation focus to the incorporation of more math content, transport phenomena, biological systems, and molecular bioengineering in the BIOEN core is more reflective of our current faculty's specialization areas and also showcases the emerging areas of bioengineering that are unique from other departments.

Industry Input on Specific Topics and Skills

Although input from industry did not shape the design of the curriculum per se, industry opinion helped shape some of the specific topics that will be addressed in the new courses. Providing students with the knowledge and skills desired by industry will enable our department to address concerns about preparation for the job market. Many core courses provide an opportunity to teach "hard skills" that students can later use to market themselves during the job search. We expect that the results of the workshop presented below will be interesting to other bio/biomedical engineering educators who likewise have students who are interesting in pursuing a career in industry.

Methods

We attended an educational workshop at the 2010 Biomedical Engineering Society Conference, which featured panelists from a wide range of biomedical companies. The goal of this workshop was to gain an understanding of industry perspectives on learning outcomes for undergraduate biomedical engineering programs. Over the span of six hours, three different panels discussed what they would like bioengineering undergraduates to know regarding problem solving, laboratory techniques, and modeling.

Results

The major charges from industry regarding what bioengineering programs should teach their students include: 1) oral presentation, team work, and communication skills, 2) stringent lab documentation practices, 3) fundamentals of the FDA regulatory process, and 4) statistical analysis techniques.

Assessing the New Curriculum: Current Student Feedback

Feedback sessions from 2009 and 2010 involving current seniors, already described, were used to obtain qualitative data regarding student satisfaction with specific proposed curriculum changes. A consensus was reached that the addition of a second Capstone option, where students can work in teams on their projects (Appendix A and B), was an excellent idea. Students stressed that they wanted both options (individual and team-based) to be available to future students. They also supported the idea of creating a 3-credit freshman-level class to introduce bioengineering in the context of engineering design, in replacement of the first course of the old BIOEN program, a 2-credit "BIOEN Tools" class, which taught some specific technical skills but did not provide any kind of introduction to the bioengineering field (Appendix A and B). Some students in 2009 expressed concern about removing the Java programming CSE course requirement from the curriculum. However, the faculty elected to establish this as an elective course so students still have the option of taking it if desired.

Assessing the New Curriculum: Industry, Academic Colleagues, and Student Alumni Feedback

Methods

Web-based surveys were distributed via email to industry affiliates, academic colleagues in bio/biomedical engineering undergraduate programs, and student alumni. Industry affiliates from a wide range of biomedical companies (i.e. large, medium, small) and academic colleagues from a variety of different types of institutions (i.e. public, private, R1, four-year technical college) were surveyed (response rate 72%). Student alumni from graduation years 2006, 2007, 2008, and 2009 were surveyed (response rate 30%). Participants were asked to provide feedback on the proposed changes to the bioengineering undergraduate curriculum (Appendix A and B). All responses were submitted anonymously via the UW Catalyst Web Tools.

Results

After reviewing the changes in our curriculum plan, survey respondents were asked to rate whether they considered the new curriculum to be significantly improved over the old curriculum (Figure 2). All surveyed groups responded with an average rating above a neutral level 3.

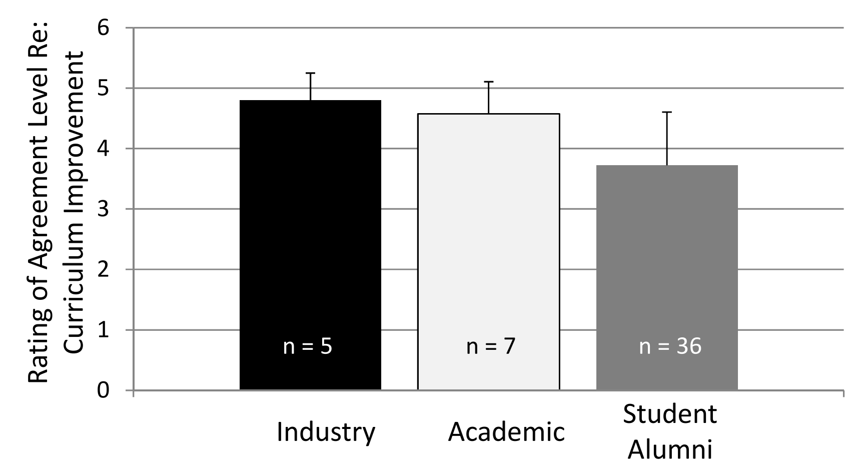

Figure 2. Ratings submitted by industry, academic, or student alumni affiliates reflecting their agreement level as to whether the new curriculum plan is significantly improved as compared to the old curriculum (5 = strong agreement, 1 = strong disagreement). Data are displayed as mean + standard deviation.

Student alumni were also surveyed with regards to whether they would have preferred to have been a student under the new curriculum plan versus the old curriculum plan. For the majority of the graduation years surveyed, student alumni agreed that they would have rather received their bioengineering education under the new curriculum plan (Figure 3).

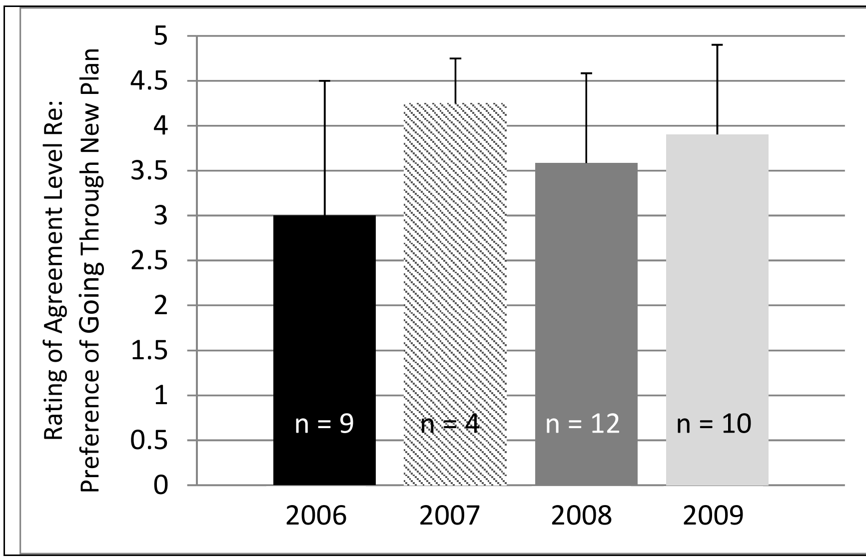

Figure 3. Ratings submitted by UW bioengineering student alumni reflecting their agreement level as to whether they would have preferred to go through the new curriculum as compared to the old curriculum plan in place when they were students (5 = strong agreement, 1 = strong disagreement). Data are displayed as mean + standard deviation.

Conclusions

In this work, we present an approach for undertaking a thorough examination of undergraduate bioengineering curriculum from a variety of perspectives. Preliminary effectiveness of the bioengineering curriculum revision, as indicated from the positive responses from industry, academic colleagues, and student alumni serves as an initial indication that our integration of results obtained from the multiple means of assessment allows for in-depth analysis and well-informed revision. Although future assessment of the success of curriculum changes implemented in our department will be needed as the new courses are phased in (starting Jan. 2011), we propose that the methods of program analysis described in this work may be useful for other departments similarly motivated to evaluate their own curriculum. In addition to specific assessments of individual course outcomes, future work involves a survey of the employers of student alumni, in order to assess how alumni are performing after graduation. We anticipate that feedback from student alumni employers will provide another useful method to gauge the effectiveness and rigor of our new program.

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Appendix A

Category	Old Curriculum Courses	Old Curriculum Credits	New Curriculum Courses	New Curriculum Credits
Bioengineering Core Courses	BIOEN Tools	2	Introduction to BIOEN Problem Solving - ethics and engineering design process	3
	Systems Analysis	4	Biochemical Molecular Engineering	3
	Instrumentation	4	Biomedical Signals and Sensors	3
	Signal Processing	4	Biomedical Signals and Sensors Lab	2
	Physiology I	4	Biotransport I (Momentum/Heat)	3
	Physiology II	4	Solid and Gel Mechanics	3
	Molecular BIOE	4	Fluids and Biomaterials Lab	2
			Biotransport II (Mass Transport, Kinetics, Thermodynamics)	3
			Systems Analysis and Control System Design	3
			Mass Transport and Systems Lab	2
			Failure Analysis and Human Physiology	4
	TOTAL	**26**	**TOTAL**	**31**
Capstone	Introduction to BIOEN Capstone	4	BIOEN Capstone Fundamentals	3
	Individual Research-Design Project	8	(Individual-based Research-Design Project), OR (Individual Research Component Plus Team-based Design Project)	10
	TOTAL	**12**	**TOTAL**	**13**
BIOE Senior Electives	**(VARIOUS) TOTAL**	**15**	**(VARIOUS) Total**	**15**
Engineering Fundamentals	Java Programming I	4	MATLAB Programming	4
	Java Programming II	5	Now taken as an elective	
	Electrical Engineering Fundamentals	4	Encompassed in BIOEN Core	
	Thermodynamics	4	Encompassed in BIOEN Core	
	TOTAL	**17**	**TOTAL**	**4**
Approved Engineering Electives	**TOTAL**	**3**	**TOTAL**	**9**
Mathematics	Calculus I	5	Calculus I	5
	Calculus II	5	Calculus II	5
	Calculus III	5	Calculus III	5
	Differential Equations	3	Differential Equations	3
	Matrix Algebra	3	Matrix Algebra	3
	Statistics	4	Statistics	3
	TOTAL	**25**	**TOTAL**	**24**
Natural Science	General Chemistry I	5	General Chemistry I	5
	General Chemistry II	5	General Chemistry II	5
	General Chemistry III	5	General Chemistry III	5
	Organic Chemistry	4	Organic Chemistry	4
	Mechanics	5	Mechanics	5
	Electromagnetism	5	Electromangetism	5
	Waves	5		
	Biology I - Genetics	5	Biology I - Genetics	5
	Biology II- Cell Bio	5	Biology II - Cell Bio	5
			Biology III - Mammailian (and Plant) Physiology - sensory and circulatory systems, chemical controls, gas exchange	5
	Biochemistry	3	Encompassed in BIOEN Core	
	TOTAL	**47**	**TOTAL**	**44**
Written and Oral Communications	English Composition	5	English Composition	5
	Technical Writing	3	Technical Writing	3
	TOTAL	**8**	**TOTAL**	**8**
Arts and Humanities	**(VARIOUS) Total**	**24**	**(VARIOUS) Total**	**24**
General Electives	**(VARIOUS) Total**	**3**	**(VARIOUS) Total**	**8**
		Total Credits		**180**
		Total Credits in Major		**72**
		Total Engineering Credits		**69**

Appendix B

	Old Curriculum	New Curriculum
Attracting Students Earlier in Academic Career	Curriculum did not have a "gateway" BIOEN survey course tailored specifically towards freshmen and sophomores.	New large lecture and discussion-based course with no prerequisites, BIOEN Problem Solving, appeals to underclassmen by introducing problem solving techniques, self-directed inquiry, engineering ethics, social constraints, and the engineering design process.
	No forum to discuss emerging areas of bioengineering and bioengineering-specific content early in undergraduate career.	Better emphasizes emerging areas of Bioengineering, as unique from all other departments.
Math Rigor and Response to Industry Preference	2 quarters of Java programming required.	1 quarter of MATLAB programming required. MATLAB and LabView are integral to lab courses of junior core.
	ODEs and PDEs introduced outside departmental classes, subsequently represented in BIOEN core.	ODEs and PDEs well integrated throughout BIOEN core (Solid and Gel Mechanics, Biotransport I, Biotransport II).
	Senior electives largely independent of core courses.	Senior electives better build upon core topics and apply them to various emerging BIOEN problems.
More Molecular Content	OChem usually taken during senior year.	OChem fits in sophomore year.
	2 quarters of biology required.	A full year of biology is completed by the end of sophomore year.
	Biochemistry often not taken until senior year.	Better integration of biochemistry topics relevant to bioengineering with new Biochemical Molecular Engineering course. This course is required and taken at the end of the sophomore year.
	Introductory-level Biomolecular content integrated into core.	New Biochemical Molecular Engineering course describes macromolecule structure, synthesis, and integration.
		Biotransport I and II further focus on molecular and biological systems.
Laboratory Applications Rigor	Labs built into each core course; 2 separate labs per quarter.	One lab per quarter that is designed to integrate the content from the quarter's two core BIOEN lecture-based courses and provide students with a hands-on opportunity to apply their knowledge in a meaningful way.
Elective Rigor	Senior electives not coordinated into specific concentration areas.	Area of Concentration Required: students now take 15 credits of senior electives in a concentrated bioengineering topic, i.e. molecular and materials bioengineering, cells tissue and systems bioengineering, and diagnostics and therapeutic instruments. 9 additional credits of electives are required; students encouraged to take courses outside the department which coordinate with their chosen BIOEN concentration area to satisfy this requirement.
	Electives sometimes survey-type courses.	Electives now build upon the rigorous engineering and math content in the core.
Engineering fundamentals	17 credits of engineering fundamentals are required, including courses in electrical engineering, thermodynamics, and Java programming.	The only external engineering fundamentals course is MATLAB programming, which is more relevant to bioengineering than Java. Necessary engineering fundamentals covered in BIOEN core. Students still may take electrical engineering and Java programming as engineering electives.
Capstone Senior Design Experience	Students work on a year-long individually-based design project, often in a BIOEN or affiliated research laboratory.	Both individual and team-based options are available. Individual option is one-year long. Team-based track involves a two-quarter long individually-based research experience and a separate two-quarter long team design experience.
Ethics in Bioengineering	Ethics addressed in 2 junior-level core courses and senior-level Intro to Capstone course.	Methods for ethical analysis introduced in freshman-level Intro to BIOEN course and applied in subsequent courses throughout BIOEN curriculum, including Capstone Senior Design sequence.
Professional "Soft Skills" (team work, communication skills)	Team work integral to core upper-level lab classes, poster and written report required for Capstone course.	Team projects implemented from freshman year through senior year, oral presentation required in addition to poster and written report for Capstone; Capstone now has option for multi-disciplinary teams.