

Zero-Based Curriculum Revision in Biological Engineering: Challenges for a New Century*

TERRY H. WALKER, CAYE M. DRAPCHO and WILLIAM H. ALLEN

Department of Agricultural and Biological Engineering, Clemson University, Clemson, SC 29634, USA.

E-mail: walker4@clemson.edu

To keep pace with rapid advancements in biology in the 21st century, a zero-based undergraduate curriculum revision was conducted at the Clemson University Biosystems Engineering program that incorporated more advanced biological sciences and biological engineering design while maintaining the basic engineering courses. The zero-based review incorporated surveys to both graduating seniors and advisors from biotechnology and the biopharmaceutical industry.

Keywords: curriculum reform; biosystems engineering; portfolio

INTRODUCTION

A ZERO-BASED REVIEW of the curriculum requires utilizing inputs from students, industry advisors and faculty based on strengths of the previous curricula, but emphasizing that significant changes need to be administered from the ground up based on content that better suits today's rapidly changing needs.

Nine months for a zero-based curriculum revision was the scenario set by the Provost in a massive overhaul of all undergraduate curricula at Clemson University. The target with maximum credit hours of 120–128 has been set. We will reduce this from 135 to 128 hours after many changes including deleting 10 hours of electives. Our life science course requirements include basic biology, microbiology, biochemistry (all with laboratories), and the recent addition of an advanced biology requirement option (selected courses from genetics, cell biology, industrial microbiology, etc.) in the applied biotechnology concentration. General education requirements were reduced university-wide, but the possible addition of two portfolio hours was suggested (one in the freshman year to begin the process and one in the senior year for completion). The student would save their portfolio information to CD to take with them at graduation. The portfolio would also serve as an assessment tool for university review.

The biological engineering curriculum and innovative changes have been addressed for land-grant universities in the last decade [1, 2] including enhancement of curriculum with the addition of numerical modeling techniques at the undergraduate and graduate levels [3–5]. Change to a more

efficient biological engineering curriculum was accomplished by reducing overall hours and ultimately moving toward more theory-based, bio-based and hands-on applications that allow for diverse opportunities at graduation. An advanced life science or biotechnology course was also added to strengthen communication skills in biology, which also distinguishes the program from other undergraduate engineering programs now considering the addition of biochemistry introductory courses (e.g. chemical and environmental engineering). The time is now right for critical changes to take place. The time is now for zero-based review, which is a process that should be repeated as often as possible to keep abreast of the amazing pace of technology in biology-based engineering and science professions.

Our zero-based review began with establishing core concepts of biosystems engineering, including the fundamental aspects of transport phenomena related to biological systems. Several courses on the verge of being dated were then deleted. New courses were added and several courses changed substantially based on the teaching of core concepts. The next step was to diversify the curriculum to encourage obtaining minors including environmental science, biomedical engineering (bioengineering), and a life science cluster, with cross-listed courses. Pre-medicine is certainly another very attractive option where biological engineering students with GPA's higher than 3.0 enjoy nearly 80% acceptance rate to medical schools. The next step considered a modular teaching system, where specific module topics are developed from theory-based applications in biological systems engineering to be taught in the appropriate course. The key element must be to ensure that module ideas are first developed by brainstorming current concepts and applications and are not

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based solely on material previously taught. The module information would ultimately be accessible electronically for review by students progressing through the program, if the course instructor chooses to do so.

Finally, courses were proposed in senior engineering and science options that would apply to new BS/MS five year curricula, where six hours of senior/graduate level courses are applied to a master's degree in biological engineering for students accepted after their junior year. The department would also provide engineering expertise to a newly proposed biotechnology BS/MS degree program (offered through the genetics and biochemistry department). Undergraduate research should be heavily encouraged and would serve as an effective recruiting tool. Suggested MS curricula would diversify the student's knowledge by requiring at least one course from the following areas: biological engineering, advanced life sciences, mathematics and statistics, other engineering, and advanced (professional) writing. A course in entrepreneurship, business management or engineering economics would also be encouraged.

A new movement at Clemson to tie together the biological based fields was established and tentatively named Bio3, which establishes research emphasis in three areas: (1) biotechnology (e.g. CU Genomics Institute), (2) biomedicine (e.g. Bioengineering) and (3) bioprocess technology (e.g. Biosystems and Chemical Engineering programs) all with overlapping areas in biomaterials and outreach that includes an established DNA learning center.

A zero-based curriculum revision was conducted for the biosystems engineering program at Clemson University to accomplish a needed thorough revision process that should occur every five to ten years to keep pace with a rapidly evolving field of biology-based engineering, while achieving a recently required university-wide reduction in course hours for all programs at Clemson University.

PROGRAM HISTORY

The Clemson University Biosystems Engineering program developed out of a traditional Agricultural Engineering program that originated in 1933. Similar to many other programs around the country, particularly in peripheral states to the agricultural belt in the Midwest, enrollment suffered in the 1980's due to the end of a very successful 'green' revolution that depleted initial fears of food shortage post World War II. A shift from an applied engineering role concerning primarily plant, animal, soil and water engineering to a biological science-based curriculum that is more comparable to chemical and environmental engineering with their sciences based primarily in basic chemistry and environmental sciences, respectively.

In the 1980's, the department contained four

concentration areas, one of which was food engineering, which was later removed due to low enrollment. In the late 1980's, two of the concentration areas were replaced with Applied Biotechnology (AB) and Natural Resources and Environment (NRE) areas when student enrollment numbers were the lowest in the program's history due to a decrease in traditional agricultural engineering related employment opportunities. However, the traditional Agricultural Engineering (AE) area was maintained as the third concentration, but recently removed with the new curriculum changes. Enrollment in biosystems engineering steadily increased in the 1990's with previous significant changes made toward a biologically-based engineering curriculum. The current enrollment has been steady and partially shifting toward the applied biotechnology concentration.

The biological sciences have developed rapidly since the initial age of biotechnology with the established areas of genomics, proteomics and metabolomics, which have led to many new patents, primarily in agricultural and medical biotechnology, and have initiated exciting new areas of gene therapy, regenerative medicine, and biopharmaceutical engineering.

Another graduate program in biomedical engineering under the name of Bioengineering was developed at Clemson in 1963 (one of the first world-wide) within a separate department that is presently administered under the College of Engineering and Science (CES). The Biosystems engineering program, which focuses more on bioprocessing and natural resources engineering is jointly administered through the College of Agriculture, Forestry and Life Sciences (CAFLS) and CES.

INDUSTRY SURVEY OF CURRICULA

A survey of the current curricula was given to two groups. The first group targeted the NRE and AE concentrations and was conducted at a South Carolina state ASAE State Section meeting held in Columbia, SC in May 2004. The second group targeted primarily the AB and NRE concentrations and was conducted via email to selected industry advisory board from industries including Amgen, Martek Biosciences, Meadwestvaco and Sigma Genesys. Although the faculty voted to remove the AE concentration, the concentration was still evaluated by the industry panels for their feedback.

The survey contained four sections including a profile section, ABET Eleven section, Biosystems engineering concentrations section, and a comments section that requested the reviewers to list ten criteria that would suggest strengths and improvements to the program to better prepare engineers for the industry.

Overall, thirty-one participants responded to the survey with the following profile:

- 88% were practicing engineers and 69% were licensed engineers;
- 65% were involved in engineering design and 35% were in engineering management;
- 23% were employed by private industry while 50% were public sector, 19% were consulting engineers and 15% were involved in the regulatory agencies;
- 34% were involved in environmental industries, 20% in biotech industries and 46% in agricultural industries;
- 62% graduated pre-1989 while 81% graduated from a Biosystems (formerly Agricultural) Engineering type curriculum and 50% graduated from Clemson University.

The 'ABET Eleven' outcomes were eleven positive statements rated on a scale of one to five. The average response on these eleven statements was 4.4, a very favorable result, indicating that the curriculum has traditionally been very effective in accomplishing the eleven outcomes adopted by ABET as indicating a 'good' curriculum/program. The sections related to the three curriculum concentrations labeled AE, NRE and AB were structured and scored in the same manner as the ABET Eleven. The average responses for these three sections were 4.0.

Suggestions were made for improvement to meet biosystems engineering and environmental industry goals and are based somewhat on frequency:

- incorporate greater process control, PLC logic, and computational capabilities from a bioprocessing point of view to better prepare students for an increasing demand for automation and robotic devices common to biotechnology;
- greater exposure to real-life problems in the industry with suggestions of more contact through technical tours, invited speakers from industry, form design teams with actual industry problem identified and greater encouragement of internship or particularly co-op experience;
- increase emphasis on project management courses and marketing skills to suit both scientific curiosity and meet profit margin objectives;
- emphasis on leadership and team activity with suggestions that design teams are formed with industry input with team members that choose a leader, design engineers and a marketing engineer;
- greater hands-on experience in bioreactor design and sterilization issues including capabilities not only in microbial and mammalian systems, but also experience with plant and insect cell systems;
- greater emphasis on recovery and purification technologies normally performed by biochemists, but at the engineering level;
- include site preparation design, storm water management, groundwater flow and waste water systems, structural design (especially concrete) and soil mechanics;
- include environmental regulations and a general

knowledge of government and 'common law principles';

- maintain a broad curriculum especially with shrinking hours without removing engineering courses, but allow specialization if possible.

Results indicate that because most of the respondents were at least mid-career, the traditional curriculum ranked well with current ABET 'outcomes' to which the current curriculum is held. The curriculum has traditionally been broad and based on fundamentals. The insertion of emphasis/concentration areas in 1989 represented an attempt to allow some specialization without losing the breadth of the program. That principle still dictates to a significant degree the philosophy of the current curriculum. Career experience has not changed the respondents' ideas regarding curriculum fundamentals, but may be responsible for the call for communication skills and familiarity with the real world of regulatory and governmental controls and business/project/personnel management.

Clearly, the industry panelists emphasize greater real-world, hands-on problem solving experiences that also include project management, marketing and teamwork goals. To address these concerns from a zero-based review, the content of all courses was mapped within biosystems engineering. For instance, greater emphasis on biosystems engineering process control may be achieved in the instrumentation courses. Specific topics in bioreactor, downstream recovery and purification operations will be further developed in several courses including the kinetics, biochemical engineering and bioprocessing laboratory courses to meet the hands-on objectives. Developing a rigorous senior capstone design course that incorporates much of the suggestions given by industry reviewers will be suggested in a format that emphasizes the team aspect with a chosen team leader and a specific faculty member who oversees the progress. Specific roles would be given for the team members to include marketing engineering. Several courses with project management and marketing goals will be emphasized under the flexible senior engineering option courses.

SENIOR STUDENT CURRICULA SURVEY

With any major changes to a curriculum, the student input must be closely noted to direct the program not only with the movement of the field, but with the student interest since they will ultimately mold the field in the future. Many of the students moving into this overlap of basic biological sciences and engineering are very bright and tend to take a strong interest in the field and its developing curricula. A strong creative instinct often exists and is highly regarded since the developing industries are in great need of new ideas to solve complex problems inherent of engineering

Table 1. Average score from exit survey for class of 2003–04

Chemistry	3.0
Computer utilization	3.0
English composition/Writing	3.4
Engineering (major field)	2.7
Engineering (other fields)	3.3
Social science/Humanities	3.5
Mathematics	3.0
Physics	3.0

within biotechnology. Although some surveys are evident as a ‘venting’ tool for disgruntled students, many suggestions for improvement are often extremely helpful for shaping the curricula of the future. The student surveys are given to both students

entering the discipline and students graduating. The student ‘exit’ surveys are given to graduating students. The survey is accompanied by an exit interview to better interpret the results and to accomplish additional feedback that may otherwise be lost through a written format.

As with the ABET Eleven, part of the exit survey instrument was based on an opinion ranking of one (inadequate) to five (too much) of areas of the curriculum. These areas and their average score for the class of 2003–04 are shown in Table 1.

One question ranged from ‘too specialized’ (1) to ‘about right’ (3) to ‘too general’ (5). The average score was 3.8, indicating student opinions were between approximately correct and somewhat

BIOSYSTEMS ENGINEERING (BE) CURRICULUM
Applied Biotechnology and (Natural Resources and Environment) CONCENTRATIONS
 September 2004 (Advising Version)

FRESHMAN YEAR			
ENGR 102 Introduction to Engineering (portfolio)	2(1,3)	ENGR 130 Intro Engr Design/Problem Solving	2(1,3)
CH 101 General Chemistry ¹	4(3,3)	CH 102 General Chemistry ¹	4(3,3)
MTHSC 106 Calculus of One Variable I ¹	4(4,0)	MTHSC 108 Calculus of One Variable II	4(4,0)
ENGL 103 Composition I or AP Test	3(3,0)	PHYS 122 Physics w/Calculus I ¹	3(3,0)
Humanities/Social Requirement ¹	3	Humanities/Social Requirement ¹	3
	16		16
SOPHOMORE YEAR			
(BE 222 Surv Soil/Water Res)	2	BE 214 Introduction to BE	2(1,3)
BIO SC 103 or 110 ¹	4(3,3)	MICRO 305 ^{1,2,3} General Microbiology	4(3,3)
MTHSC 206 Calculus of Several Variables	4(4,0)	MTHSC 208 Intro Ord Differential Equations	4(4,0)
PHYS 221 Physics w/Calculus II ¹	3(3,0)	EG 209 Intro to Engineering/Computer Graphics	2(1,3)
EM 201 Statics	3(3,0)	EM 202 Dynamics	3(3,0)
	14	E&CE 307 Basic Electrical Engineering	2(2,0)
	(16)		17
JUNIOR YEAR			
BE 410/610 Biological Kinetics/Reactor Modeling	3(2,3)	BE 313 BE Heat and Mass Transport	3(3,0) 3
CH Organic Chemistry Option ^{1,2}	4	BCH Biochemistry Option ^{1,3,5}	4
EM 304 Mechanics of Materials	3(3,0)	BE 415 Microcomputer/Instrumentation	4(3,3) 4
		BE 428/628 Biochemical Engineering	3(3,0)
ME 310 Thermodynamics/Heat transfer	3(3,0)	(BE 314 BE Mech Unit Operations)	3
CE 341 Introduction to Fluid Mechanics	4(3,3)	(BE 322 Watershed Hydrology/Sedimentology)	3
Humanities/Social Requirement ¹	3	COMM 250 Public Speaking	3(3,0) 3
	17		17 (16)
SENIOR YEAR			
BE 474 Engineering Project Management	2(1,3)	BE 475 Capstone Design Project	2(1,3) 2
BE 429 Bioprocess Engineering Design	3(2,3)	Bioscience Option ^{1,3,5}	3
Machine Design (BE 414 or ME 306)	3	455/635 Applications in Biotech Engr	3(2,3)
Engineering Option ^{1,2,3}	3	Engineering Option ^{1,2,3}	3
(BE 364 Non-Point Source Pollut Manage Control)	3	(BE 423 Engr Sys Soil Water Management)	2
Literature Requirement ¹	3	(CE 321 Geotech)	4
Humanities/Social Requirement ¹	3	(Structural Design Requirement)	3
	17	Humanities/Social Requirement ¹	3
			14

128 Total Semester Hours
 () represent Natural Resources concentration differences, ____ represent Applied Biotech concentration differences

¹See Policy on Humanities and Social Sciences for Engineering Curricula.
²Choose CH 223 and 227 (preferred) or CH 201;
³Choose BCH 301/302 or BCH 305/306 (preferred)
⁴Choose Senior level engineering course from BE 414, ME 306 or approved engineering course
⁵Choose from MICRO 415/611; BIO SC 458/658 (or BE 658), 459 or 461; GEN 306, 305 or 418/618; BCH 421/623 3(3,0) (Take 600 level version if accepted into BSMS program)

Students are urged to complete a minor (such as Life Science Cluster, Bioengineering or Environmental Engineering and Science), participate in the Cooperative Education program and/or the Biosystems Intern program (BE 570), and the Study Abroad program. Those with medical career interests should consider graduate study and/or medical school.

^{1,2} Life Science Cluster Minor (BIOCH, GEN, BIO SC, MICRO)
³ BEOE Minor courses (BEOE 302, 320 and 401)
⁴ EE&S Minor courses** (CH 223, MICRO 301, EE&S 401, 402 + one other EE&S 400 level)
⁵ Pre-med⁵: 16 hrs chemistry (CH 101,102 (or AP test), 223,227,224,228 and BIOCH 301,302 recommended), 8 hrs biological sciences (BIOL 103,104 or 110,111 or AP test), 8 hrs physics (PHYS 122,124,221,223) and 1 calculus course

⁶None.
⁷All Biosystems Engineering students must have a cumulative engineering grade-point ratio of 2.0 to enroll in any 300 or 400 level BE courses.

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Fig. 1. Proposed Biosystems Engineering undergraduate curriculum.

too general. While this fact is not to be discounted, it may relate to students that typically wish they could take more courses they see as directly related to their area of interest, which is generally more applied. One question sought the students' satisfaction level related to the overall curriculum, ranging from 'totally dissatisfied' (1) to 'completely satisfied' (10). The student response to this question averaged 7.25, indicating a significant degree of satisfaction.

RECENT CURRICULAR CHANGES

The changes made by the curriculum committee and voted on by the whole faculty during dedicated retreats were compiled over a year with the input from the student and industry surveys. Figure 1 shows the proposed curriculum and was presented to the curriculum committees of both colleges for approval in late Fall, 2004. The courses for both concentrations are listed for each semester with the basic engineering course, followed by basic science and mathematics courses. Other engineering courses, humanities and related courses are then listed for each semester.

The two concentrations are represented to show differences noted by underlining the Applied Biotechnology concentration, and the Natural Resources and Environment concentration differences are shown in parenthesis. The footnotes represent options and how the proposed minors and premedicine option fits in the curricula. The Engineering options during the senior year may be taken towards a 5-year BS/MS degree if the student meets requirements and is accepted after the junior year. The two concentrations are common in the first two years and separated by only 18 hours, primarily in the junior and senior years.

The significant changes from the older curriculum are summarized as follows:

- deletion of agricultural engineering (AE) concentration;
- addition of basic biology and advanced biological sciences option to the AB concentration and basic microbiology to the NRE concentration;
- addition of basic kinetics, bioreactor design and bioprocess design courses;
- deletion of 10 credit hours of electives;
- deletion and combination of existing biosystems engineering courses;
- engineering option courses designed for

encouraging minors in environmental, biomedical or related emphasis areas creating a significant avenue for proposed BS/MS degree programs in biosystems engineering and related areas;

- biological and biochemical sciences with required laboratories encourage greater overlapping interest with pre-medicine, life sciences and biotechnology options;
- addition of geotech, structural design components to the NRE concentration;
- addition of a machine design component to both concentrations to enhance biomechanical and basic machine design content.

CONCLUDING REMARKS

The Clemson Chemical Engineering department recently made significant changes to their undergraduate program with additions of industrial microbiology and basic biochemistry. These changes are similar to the changes made to the biosystems engineering curricula in the early 1990's to strengthen basic biological sciences at the undergraduate level. Also, the Clemson Bioengineering department has recently proposed starting an undergraduate program. In essence, three science-based engineering curricula would exist with greater emphasis on biological sciences. This trend appears to be happening on the national scale as indicated by the American Institute of Chemical Engineers (AIChE) creation of a Biological Engineering Division in addition to existing societies including the Institute of Biological Engineers (IBE). The addition of basic biology, advanced biology option and greater emphasis on kinetics and bioprocessing courses in the applied biotechnology concentration of biosystems engineering further strengthens the biological base and it is important to stay ahead of the wave in this rapidly-growing interest area. Incorporation of ideas suggested from student and industry surveys must be considered to improve content within the biosystems engineering courses.

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Terry H. Walker has over ten years of experience in bioprocess engineering. His research and teaching interests are focused on fermentation and bioseparation technologies. He and his students have worked specifically on bioconversion of feedstock materials from natural byproducts to produce pharmaceutical and nutraceutical products with a focus on thermodynamic and numerical kinetic modeling of extraction processes. He teaches courses in biochemical engineering, bioprocess engineering design and biotransport processes. He is currently chair of the Biosystems Engineering curriculum committee and serves on the College of Engineering and Science curriculum committee at Clemson University.

William H. Allen graduated from Clemson University (BS/1966 and MS/1969) and Ph.D. from the University of Tennessee in 1972. He worked at Mississippi State University (1972–76) and joined Clemson University in 1976, where he is currently the Chair of the Agricultural and Biological Engineering Department.