Outcomes Based Curriculum Development in a New and Emerging Biomedical Engineering Program

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I. Introduction

The Biomedical Engineering program at North Carolina State University has been emerging since the early 1990s, when it began as a graduate minor. In 1994, the Department of Biological and Agricultural Engineering (BAE) began offering the B.S. in Biological Engineering (BE) and included a concentration in Biomedical Engineering. Due to the overwhelmingly positive response of students to the Biomedical Engineering Concentration, the BAE faculty voted in 1997 to develop a separate B.S. in Biomedical Engineering (BME). In May 2001, the Board of Governors of the University of North Carolina system approved the establishment of the B.S. in BME, and the new degree program, which is strongly supported by both the College of Engineering and the College of Agriculture and Life Sciences at NC State and is the only state-supported B.S. in BME in North Carolina, became effective in August 2001.

II. Development of Program Educational Objectives, Outcomes, and Assessment Methods

The initial program educational objectives (PEOs) for the BME program (Figure 1) were exact duplicates of the PEOs for the BE degree with "biomedical" substituted for "biological" where appropriate. These PEOs were developed in spring 2001 with input from the BAE faculty and from the BAE Advisory Board, which included two biomedical engineers. This approach provided a reasonable first step since the BME degree evolved from the BE degree. The original outcomes (not shown), for both the BE and BME degree programs, were Criteria 3a-3k as defined by ABET (http://www.abet.org).

In September 2001, faculty from other disciplines within the College of Engineering (mechanical, textile, industrial, chemical, and electrical engineering and computer science) and other colleges (Veterinary Medicine and Physical and Mathematical Sciences) were invited to serve on the BME Curriculum Committee. The BME Curriculum Committee met regularly throughout the 2001-2002 academic year to develop PEOs that were more specific for the BME degree program. The first step in the process involved reducing the number of PEOs from eight to five by developing ones that were more general and overarching. After reaching consensus on these five PEOs (Figure 2), the committee turned its attention to developing outcomes, i.e. measurable statements that can be used to assess whether students are achieving the objectives of the program. The group decided that it would be more meaningful to develop outcomes that were appropriate for each objective and then map these to ABET Criteria 3a-3k to ensure that the criteria for accreditation were also being met rather than simply adopt ABET Criteria 3a-3k and try to map them to the PEOs. The initial attempt resulted in 34 outcomes for the five objectives

– an overwhelming number for a small group of faculty to assess! Further discussions resulted in reducing the number of outcomes to 16, a much more manageable number. Most of the reductions occurred by eliminating similar outcomes or by combining several comparable outcomes into a single statement. Examples of the changes that were made due to overlapping outcomes are shown in Figure 3.

While developing an assessment plan, consideration was given to developing assessment methods that would work for multiple outcomes, to using both direct and indirect measures, and to finding and using measures that were already in place. NC State University already has a number of indirect assessment measures, e.g. senior and alumni surveys, in place that include questions that have been mapped to ABET 3a-3k. These were included in the assessment plan wherever they were considered to be appropriate.

For direct measures, the BME Curriculum Committee turned to course-based assessment. The plan based on the current curriculum uses six of ten required courses plus four senior electives for the assessment process, but most of the assessment process is focused on two junior-level courses and on the two-semester capstone senior design courses. These four courses are required of all students. Concentrating assessment on these courses avoids the problem of having to ensure that all possible combinations of elective courses are being equally assessed. Each course instructor is responsible for data collection, but the BME Curriculum Committee approves the actual data to be assessed in each course, e.g. exam questions that address specific program outcomes, after receiving recommendations from the course instructor. Spreadsheets and rubrics are used to simplify course-based assessment. The methods that are used to assess Objective 2 (by assessing its outcomes) are shown in Figure 4. The committee devotes one meeting each year to a discussion of results, which will lead to changes in courses that will be implemented during the following year and to changes in overall program that will be implemented over an appropriate time period given the constraints imposed by the university in terms of developing new courses and curricular changes.

During the process of developing the assessment plan (which began in early 2002), it became clear that there was still overlap across objectives and outcomes and that outcomes had been included that were not measurable. This led to further reducing the PEOs from five to four and the outcomes from 16 to 14. The current PEOS and outcomes with their ABET counterparts in terms of Criteria 3a-3k and 8 were adopted in March 2002 and are shown in Figure 5. The process that is in place for continuous evaluation and assessment of the BME program and its PEOs and outcomes is shown in Figure 6.

III. Outcomes Based Curriculum Development

The impending establishment of a new BME Department brought the BME Curriculum Committee together to accomplish another challenging task – that of developing a new, broader, and more diverse BME degree program that will better meet the needs of the students and the industrial community served by NC State and will take advantage of the opportunities made possible by the establishment of a new department with additional faculty trained in biomedical engineering. The Whitaker Foundation's Biomedical Engineering Educational Summit in December 2000, which brought together two faculty involved in the undergraduate educational program from every institution in the United States that offered an undergraduate degree in biomedical engineering, representatives from schools in the US who would soon be offering a degree program, e.g. NC State, and representatives from established biomedical engineering programs in Canada and Europe, provided a rich source of data for initial discussions about what a revised BME curriculum should look like. The program for the summit included plenary sessions on educational advances in biomedical engineering and in learning theory and on special topics in biomedical engineering. There were four workshop sessions with several breakouts available during each workshop. One of the workshops divided into breakouts based on curricular issues: biomechanics, bioinstrumentation, biosystems, cellular and molecular engineering, and biomaterials. The recommendations from these breakout sessions, which are summarized in Figure 7, were used as input for the process of revising the BME curriculum at NC State.

During this process, input was also sought from one group of constituents, juniors who are currently in the program. They were given the task of working in teams to brainstorm what the revised BME curriculum would look like given the following design constraints:

1. The NC Legislature has mandated that 4-year programs cannot exceed 128 hours of credit.

2. The curriculum must include fifty-one credit hours of courses mandated by the University and College of Engineering. These include 21 hours of humanities and social sciences courses, and a 4-hour writing course. ENG 111 and ENG 112 (Figure 8), two 3-hour courses, are to be replaced by a new 4-hour course, ENG 101, beginning in fall 2003. Other requirements include a 3-hour communications elective, 2 credit hours of physical education, 11 hours of math, 8 hours of physics, and two 1-credit-hour introductory classes in engineering and the computing environment in the College of Engineering.

3. The curriculum must include 48 hours of engineering topics, including a capstone senior design course (or courses). (The numbers in bold in the first and last columns of the curricula shown in Figures 8 and 9 indicate the number of hours of engineering topics in each course.)

4. The BME Curriculum Committee has developed objectives (broad overarching goals) and outcomes (specific and measurable things that students should be able to do when they finish this degree) for the BME program. A revised curriculum must also meet these objectives and outcomes.

5. The curriculum must fulfill the following ABET program criteria: “The structure of the curriculum must provide both breadth and depth across the range of engineering topics implied by the title of the program. The program must demonstrate that graduates have: an understanding of biology and physiology, and the capability to apply advanced mathematics (including differential equations and statistics), science and engineering to solve the problems at the interface of engineering and biology; the ability to make measurements on and interpret data from living systems, addressing the problems associated with the interaction between living and non-living materials and systems.”

One of their suggestions was to have more BME courses in the sophomore year so that students would learn more about their major before their junior year. Another suggestion was to allow students to take the statics and dynamics sequence in either Civil or Mechanical Engineering so that they would have more flexibility in terms of developing their schedules. A third suggestion was to have more biomedical engineering electives and more courses that were specifically for biomedical engineering students. A fourth suggestion was that biology should be introduced at an earlier point in the curriculum instead of organic chemistry. All of these suggestions were implemented in the revised curriculum (Figure 9, which has new courses in bold). The one suggestion that could not be achieved was that Humanities and Social Science be distributed more evenly across the curriculum. This is difficult to accomplish when it is also necessary for students to have taken most of their engineering courses (and all of the prerequisites for these courses) before taking the senior design sequence. Otherwise, the senior design courses could not be considered to be "capstone" in nature.

Although the results from the Whitaker Summit and from the brainstorming session with students were considered, the PEOs and outcomes for the BME program were the main drivers for the process of reformulating and updating the BME curriculum from that shown in Figure 8, which closely resembles the B.S. in BE and relies on courses taught in the BAE Department that are taken concurrently by both BE and BME majors, to that shown in Figure 9. By starting with overarching objectives and measurable outcomes related to each objective, the BME faculty have identified key educational program components and then focused on implementation strategies – a process that folds curriculum development and assessment together nicely. Developing a curriculum from outcomes allowed faculty to look at not just a series of courses but also at how the courses interacted synergistically to give rise to opportunities for enhanced student learning in the discipline.

The new curriculum includes a sequence of six BME electives (A-F), which provide depth in the curriculum, while the sequence of required courses provides breadth by covering computer methods (BME 201), biomaterials (MAT/BME 203), circuits with BME examples (BME 210), human physiology from an engineering perspective (BME 301 and BME 302), linear systems (BME 311), and an overview of biomedical engineering topics (BME 202) to help students decide on the BME elective sequence that interests them.

Careful consideration to the timing of when new concepts and skills are introduced and then reinforcing them throughout the entire curriculum has led not only to new course development but also to reevaluation of prerequisites for existing courses. Some of the new courses, e.g. BME 202, 301, and 302, are based on existing courses, i.e. BAE 381 and 382, which provided a direct mapping of outcomes assessment and objectives from the current to the revised curriculum. For example, Figure 4 shows the assessment methods that will be used to determine whether students have achieved Objective 2. In the revised curriculum, 2.a.i will be assessed in BME 451 and BME 452, 2.b.i will be assessed in BME 202, 2.c.i. will be assessed in BME 301, 2.c.ii. will be assessed in BME 451, and 2.d.i. will be assessed in BME 302. 2.d.ii will be revised to indicate that multidisciplinary teams in BME 451 will consist of students following different areas of emphasis (Table I) rather than different degrees.

Table I. BME Electives by Area of Emphasis for Revised BME Curriculum (Figure 9)
(New BME courses are shown in Italics.)

	Biomechanics	Biomaterials and Tissue Engineering	Biomedical Instrumentation
A	MAE 314/CE 313: Solid Mechanics	MAE 314/CE 313: Solid Mechanics	Any approved engineering course
B	MAE 308/CE 382: Fluid Mechanics	TE 463: Polymer Engineering	*BME 422: Fundamentals of Biomedical Instrumentation*
C	*BME 342: Experimental and Analytical Methods in Biomechanical Engineering Analysis*	New TC course: Chemistry of Biopolymers (no engineering content)	*BME 412: Biomedical Signal Processing*
D	*BME 441: Biomechanics*	TE 466: Polymeric Biomaterials	BME 425: Bioelectricity (revised version of BAE 485)
E	Any approved engineering course	Any approved engineering course	Selected 2 from an approved list of electrical engineering courses on control, robotics, mechatronics, etc.
F	TE 467: Tissue Mechanics	TE 467: Tissue Mechanics	

By maintaining a focus on the PEOs and associated outcomes for the BME program, the BME Curriculum Committee was able to develop a revised curriculum with ten new required courses and three new areas of emphasis, which include four additional new courses, in less than four months. Since some of the new courses evolved from existing BAE courses that are used in the current assessment process, there is a direct mapping from the current to the revised curriculum – making continuous assessment, evaluation, and improvement of the B.S. in BME a seamless process during its transition from residing in the BAE Department to its new home in the BME Department.

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Figure 1: Initial BME Program Educational Objectives

The Department of Biological and Agricultural Engineering offers an undergraduate BS degree program in Biomedical Engineering (BME). The faculty of this department in concert with constituencies have developed the following undergraduate educational objectives for the BS in BME degree.

1. To educate students for successful careers in Biomedical Engineering. Emphasis is placed upon mastering the fundamentals of engineering and biology, the ability to solve engineering problems, and understanding the creative process of engineering design.

2. To instill in the students a sense of confidence in their ability to grasp and apply engineering principles, procedures, and time management skills needed to solve complex, real-world problems.

3. To impart a sense of professional responsibility and work ethic in performing engineering tasks at a high level of expertise and accept the ethical responsibility to be accountable for the social and environmental impact of engineering practices.

4. To establish an educational environment in which students participate in inter-disciplinary activities, which will broaden their engineering education, help them develop professional interaction skills, and more effectively prepare students to work in today's integrated team environment.

5. To offer a curriculum that provides students an opportunity to become broadly educated engineers and life-long learners, with a solid background in the basic sciences and mathematics; an understanding and appreciation for the arts, humanities, and social sciences; an ability to communicate effectively with diverse audiences and for various purposes; and, a desire to seek out further educational opportunities.

6. To expose students to advances in engineering practice and research and to prepare them for opportunities in graduate engineering education or professional schools.

7. To retain faculty who are committed to the educational and research missions of the department and to acquire, maintain, and operate facilities and laboratory equipment appropriate to our engineering program.

8. To recruit students with high potentials who will contribute to the economic and social well being of North Carolina.

Figure 2: BME Program Educational Objectives – Round 2

1. To educate students for successful careers in Biomedical Engineering, emphasizing the fundamentals of engineering and biology related to basic medical sciences and human health.

2. To produce broadly educated Biomedical Engineers able to communicate effectively with diverse audiences and prepared to work in integrated teams.

3. To develop in students professional, ethical, and societal responsibility in Biomedical Engineering practices.

4. To instill in students a life-long thirst for knowledge and personal responsibility for the success of their careers.

5. To introduce students to advances in Biomedical Engineering practice and research and to prepare them for opportunities in graduate engineering programs or professional schools.

Figure 3: Examples of Overlapping Outcomes That Were Combined

July 2002:

1. To educate students to be successful in Biomedical Engineering by emphasizing engineering and biology as related to basic medical sciences and human health.
   a. Draw on knowledge of mathematics and science to solve problems at the interface of engineering and biology.
   d. Critically evaluate, analyze, and solve problems at fundamental and advanced levels by using appropriate tools.

4. To introduce students to advances in Biomedical Engineering practice and research and to instill in them a life-long thirst for knowledge.
   b. Demonstrate a desire for learning.
   c. Set career goals and develop individualized plans for advancement.

September 2002:
1.a and 1.d were combined into a single outcome for objective 1.

1. To educate students to be successful in Biomedical Engineering by emphasizing engineering and biology as related to basic medical sciences and human health.
   a. Draw on knowledge of mathematics, science, and engineering to critically evaluate, analyze and solve problems at the interface of engineering and biology by using appropriate tools.

4 b. and 4.c were combined into a single outcome for objective 4.

4. To introduce students to advances in Biomedical Engineering practice and research and to instill in them a life-long thirst for knowledge.
   b. Demonstrate a desire for learning through post-graduate career plans.

Figure 4: Assessment Methods for Objective 2

2. To produce Biomedical Engineers able to communicate effectively with diverse audiences and prepared to work in multidisciplinary teams.

   After completing the B.S. in Biomedical Engineering, students will be able to:

   a. Deliver effective oral presentations to multiple audiences, including health care and engineering professionals. (3g)
      i. *Oral presentations of capstone projects made by students in BAE 451 and BAE 452 to an audience that includes health care and engineering professionals. A faculty team has defined a rubric, which includes an assessment of each student's ability to communicate the design project effectively, that is used to evaluate these projects.* (Every semester the course is taught.)
      ii. *Employer, internship and co-op supervisor, alumni, and senior survey items related to whether current students and graduates are able to make effective oral presentations. Results of the surveys are compiled and used to inform the faculty in discussions of curricular changes.* (1 – 3 year intervals)

   b. Prepare effective written materials. (3g)
      i. *Written term projects from BAE 382 on selected contemporary human health issues, which include biomedical engineering solutions. Student ability to write an effective project is assessed by faculty with a faculty-designed rubric.* (Every semester the course is taught.)
      ii. *Employer, internship and co-op supervisor, alumni, and senior survey items related to whether current students and graduates are able to produce effective written material. Results of the surveys are compiled and used to inform the faculty in discussions of curricular changes.* (1 – 3 year intervals)

   c. Use modern engineering tools to communicate ideas with others within the engineering discipline. (3g)
      i. *Technical drawing of the SIMULINK program developed in BAE 381. Student ability to develop an appropriate technical drawing is assessed by faculty with a faculty-designed rubric.* (Every semester the course is taught.)
      ii. *2-D orthographic drawings developed by students in BAE 451. Student ability to develop an appropriate technical drawing is assessed by faculty with a faculty-designed rubric. The goal is for 100% of BME graduates to achieve this outcome at the competent level as defined by the rubric.* (Every semester the course is taught.)
      iii. *Employer, internship and co-op supervisor, alumni, and senior survey items related to whether current students and graduates are able to use modern engineering tools to communicate ideas. Results of the surveys are compiled and used to inform the faculty in discussions of curricular changes.* (1 – 3 year intervals)

   d. Work effectively in multidisciplinary teams to complete projects. (3d)
      i. *Students in BAE 382 are assigned to teams that include members from both genders, from different ethnic backgrounds (when this is possible based on the composition of the class), and with different learning styles. A faculty-designed rubric is administered to all students in this course to determine how effectively their team functioned.* (Every semester the course is taught.)
      ii. *Students in BAE 451 work on teams that include Biological Engineering (BE) and Biomedical Engineering (BME) students. A faculty-designed rubric is administered to all students in this course to determine how effectively their team functioned.* (Every semester the course is taught.)
      iii. *Employer, internship and co-op supervisor, alumni, and senior survey items related to whether current students and graduates are able to work effectively in multidisciplinary teams. Results of the surveys are compiled and used to inform the faculty in discussions of curricular changes.* (1 – 3 year intervals)

Figure 5: Current BME Program Educational Objectives and Outcomes and Corresponding ABET Criteria

1. To educate students to be successful in Biomedical Engineering by emphasizing engineering and biology as related to basic medical sciences and human health. (3a, 3b, 3c, 3e, 3j, 3k, 8)

   After completing the B.S. in Biomedical Engineering, students will be able to:
   a. Draw on knowledge of mathematics, science, and engineering to critically evaluate, analyze and solve problems at the interface of engineering and biology by using appropriate tools. (3a, 3b, 3e, 8)
   b. Identify contemporary clinical issues and be able to discuss potential biomedical engineering solutions. (3a, 3e, 3j, 3k, 8)
   c. Design and model biomedical materials, systems, and/or devices. (3a, 3c, 3e, 3k, 8)
   d. Explain basic concepts of systems and cellular physiology. (3a, 8)
   e. Design and conduct experiments to test hypotheses and to make measurements on and interpret data from living systems. (3b, 3e, 8)

2. To produce Biomedical Engineers able to communicate effectively with diverse audiences and prepared to work in multidisciplinary teams. (3d, 3g)

   After completing the B.S. in Biomedical Engineering, students will be able to:
   a. Deliver effective oral presentations to multiple audiences, including health care and engineering professionals. (3g)
   b. Prepare effective written materials. (3g)
   c. Use modern engineering tools to communicate ideas with others within the engineering discipline. (3g)
   d. Work effectively in multidisciplinary teams to complete projects. (3d)

3. To develop in students professional, ethical, and societal responsibility in Biomedical Engineering practices. (3f, 3h, 3j)

   After completing the B.S. in Biomedical Engineering, students will be able to:
   a. Demonstrate understanding of formalized ethical codes in engineering and medicine. (3f)
   b. Articulate, identify, and evaluate contemporary ethical issues in biomedical engineering and their impact on society. (3f, 3h, 3j)
   c. Demonstrate professional behavior. (3f)

4. To introduce students to advances in Biomedical Engineering practice and research and to instill in them a life-long thirst for knowledge. (3g, 3i)

   After completing the B.S. in Biomedical Engineering, students will be able to:
   a. Assess, evaluate, and reference peer-reviewed technical literature. (3g, 3i)
   b. Demonstrate a desire for learning through post-graduate career plans. (3i)

Figure 6. Continuous Process for Evaluating BME Program Educational Objectives (PEOs)

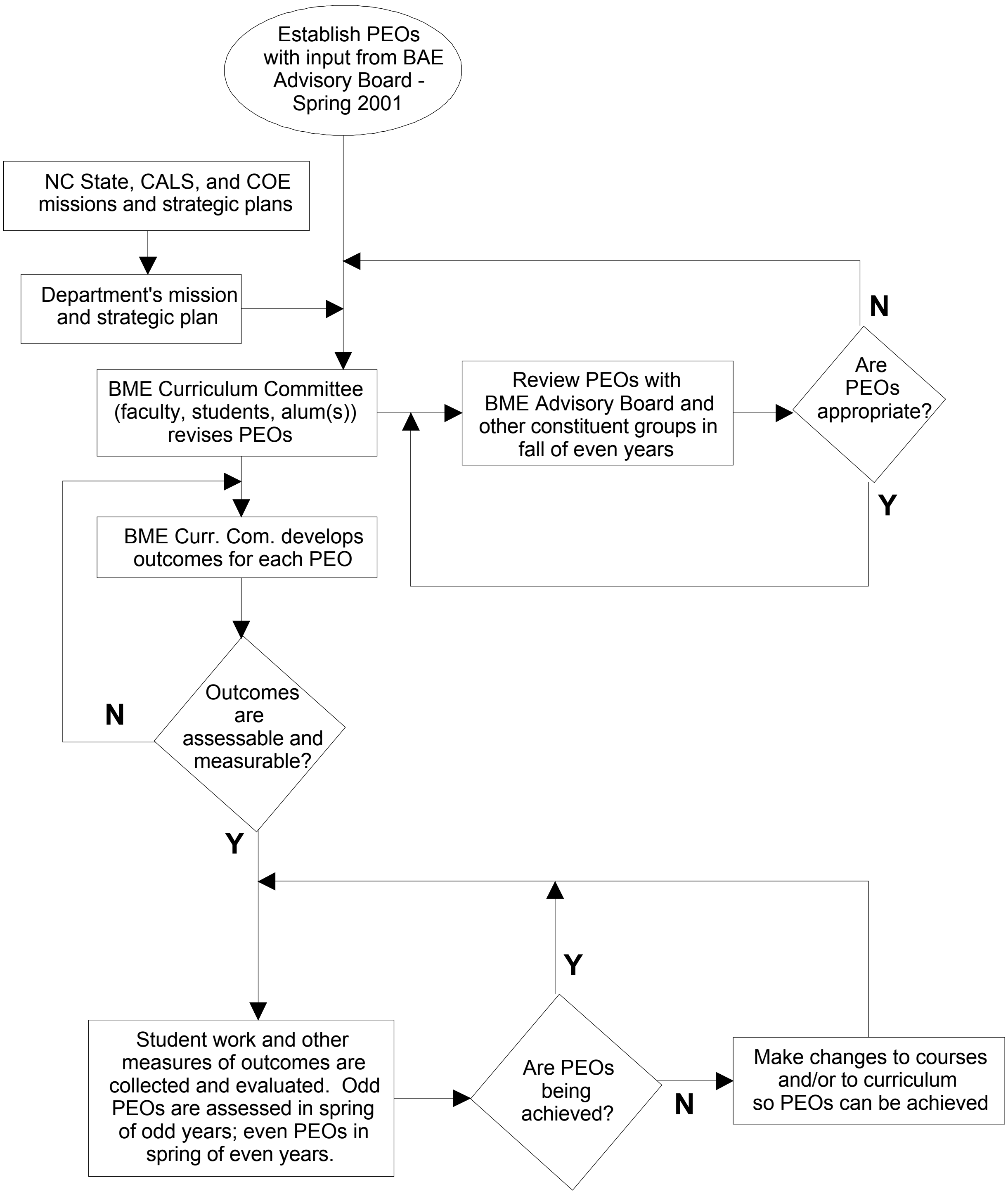

Figure 7. Selected Summary Report Recommendations from the Curriculum Breakouts at the Whitaker Biomedical Engineering Educational Summit
http://summit.whitaker.org

Breakout	Recommendations
Biomechanics	1. Statics and strength of materials should be included in curricula for all biomedical engineering students. 2. Transport phenomena and scaling laws and dimensional analysis are highly recommended but could be electives. 3. The following topics are required for a biomechanical focus: continuum concepts of solid mechanics (soft and hard tissue); continuum concepts of fluid mechanics (e.g. arterial flow); methods of computer modeling and simulation; dynamics and kinematics; experimental methods; classic thermodynamics; structure-function relationships.
Bioinstrumentation	1. All BME undergraduates should be required to take course work and lab work in bioinstrumentation. 2. The following course content is essential for all BME undergraduates: components of an instrument; sources of signals (engineering physiology); underlying physical principles; basic principles of sensing and measurements; data acquisition and characterization; amplifiers, filters, signal-to-noise ratio, and safety analyses; interactions between the instrument and what is being measured; the interface of the device with the body; problem definition with historical context; integration of components into a final design and working system. 3. BME graduates should not have to take or pass a national exam before they are allowed to graduate because such exams can suppress creativity and become quickly outdated. 4. Universities should require all BME graduates to select a specialized track.
Biosystems	1. BME students should have a 3-credit hour course in the application of linear systems theory in the context of biological and physiological systems. 2. By the time they graduate, BME students should have had: systems theory (linearity, convolution); signals (continuous, discrete); control theory (feedback, stability, non-linear methods); exposure to systems engineering tools, including time and frequency domain and modeling tools.
Cell and molecular engineering	1. BME departments should focus on the broad perspective and teach students to be life-long learners. 2. Departments should avoid launching whole new tracks per se because the field is changing too fast and courses will need to change over time.
Biomaterials	1. A biomaterials course should be incorporated into, but not required, in BME curricula at the junior level. 2. A modern biomaterials course should include traditional materials science and engineering but also address tissue properties. 3. Courses in biomaterials should involve students in the educational process by a hands-on, problem-based or design-based approach to learning. 4. A lab course or module should cover content such as corrosion dynamics, mechanical testing, polymer properties, surface characterization, and cellular or molecular interactions. 5. Case studies should be used to help place biomaterials in context with medical devices and to introduce ethical issues into the curriculum.

Figure 8. Current Curriculum in Biomedical Engineering
(Numbers in bold represent engineering credits.)

Freshman Year

	Fall Semester		*Credits*	*Spring Semester*		*Credits*	
	CH 101	Chem - A Molecular Science	3	CH 220	Organic Chemistry or	4	
	CH 102	General Chemistry Lab	1	CH 221	Organic Chemistry		
	E 101	Intro to Engrg & Prob Solvng	1	ENG 112	Comp. and Reading	3	
	E 115	Introduction to Comp. Environ.	1	MA 241	Calculus II	4	
	ENG 111	Comp. and Rhetoric	3	PY 205	Physics Engrs. & Sci. I	4	
	MA 141	Calculus I	4	BAE 100	Intro. to Biol. & Biomed. Engrg.	1	
		Economics Elective	3			16	
			16				

Sophomore Year

	Fall Semester		*Credits*	*Spring Semester*		*Credits*	
2	BAE 200	Comp. Meth. in Biol. Engrg.	2	BAE 202	Intro. to BAE Methods	3	**3**
3	MAE 206	Engineering Statics	3	MAE 208	Engineering Dynamics	3	**3**
	MA 242	Calculus III	4	MA 341	Differential Equations	3	
	PY 208	Physics Engr. & Sci. II	4	ECE 331	Electrical Engineering I	3	**3**
	GC 120	Foundations of Graphics	3	ZO 160	Intro. to Cell. Devel. Zoology or	4	
			16	BIO 183	Intro. Biology II		
						16	

Junior Year

	Fall Semester		*Credits*	*Spring Semester*		*Credits*	
3	BAE 401	Bioinstrumentation	3	BAE 315	Properties of Biol. Eng. Mats.	3	**3**
2	BAE 381	Human Physiology for Engrs.	3	BAE 361	Analytical Methods in Design	3	**3**
3	MAE 301	Engr. Thermodynamics I	3	BAE 382	Biomedical Engineering Appls.	3	**3**
3	MAE 308	Fluid Mechanics	3	MAE 314	Solid Mechanics	3	**3**
		Technical Elective	3 -4		History or Literature	3	
	PE 1XX	Fitness and Wellness	1		Physical Education Elective	1	
			16			16	

Senior Year

	Fall Semester		*Credits*	*Spring Semester*		*Credits*	
3	BAE 451	Engr. Design I	3	BAE 452	Engr. Design II	2	**2**
	ST 370	Prob. & Statistics for Engrs.	3		Engineering Elective	3	**3**
3		Engineering Elective	3		Biological Science Elective	3	
		Ethics Elective	3		Communications Elective	3	
		History or Literature	3		Any approved H&SS course	3	
		Social Science (not Econ.)	3			14	
			18				

22 **Minimum Total Credit Hours Required for Graduation = 128** **26**

Figure 9. Revised Curriculum in Biomedical Engineering
(Numbers in bold represent engineering credits.)

Freshman Year

	Fall Semester		*Credits*	*Spring Semester*		*Credits*	
	CH 101	Chem - A Molecular Science	3	ZO 160	Intro. to Cell. Devel. Zoology or	4	
	CH 102	General Chemistry Lab	1	BIO 183	Intro. Biology II		
	E 101	Intro to Engrg & Prob Solvng	1	PY 205	Physics Engrs. & Sci. I	4	
	E 115	Introduction to Comp. Environ.	1	MA 241	Calculus II	4	
	ENG 101	Acad. Writing and Research	4	**BME 102**	**Introduction to Biomedical Engineering**	1	
	MA 141	Calculus I	4		Economics Elective	3	
	PE 1XX	Fitness and Wellness	1			16	
			15				

Sophomore Year

	Fall Semester		*Credits*	*Spring Semester*		*Credits*	
2	**BME 201**	**Computer Methods in BME**	3	**BME 202**	**Introductory Topics in BME**	3	**3**
3	**MAT/BME 203**	**Intro Mat Sci of Biomaterials**	3	**BME 210**	**Analog and Digital Circuits**	3	**3**
3	MAE 206	Engineering Statics *or*		MAE 208	Engineering Dynamics *or*	3	**3**
	CE 214	Statics	3	CE 215	Dynamics		
	MA 242	Calculus III	4	CH 221	Organic Chemistry	4	
	PY 208	Physics Engr. & Sci. II	4	MA 341	Differential Equations	3	
			17			16	

Junior Year

	Fall Semester		*Credits*	*Spring Semester*		*Credits*	
2	**BME 301**	**Human Physiology for Engineers I**	3	**BME 302**	**Human Physiology for Engineers II**	3	**2**
3	**BME 311**	**Linear Systems in BME**	3		**BME elective B**	3	**3**
3		**BME elective A**	3		**BME elective C**	3	**0 -3**
	ST 370	Prob. & Statistics for Engrs.	3	MAE 301	Engr. Thermodynamics I *or*	3	**3**
		Communications Elective	3	MAT 301	Equilibrium and Rate Processes		
			15	GC 120	Foundations of Graphics	3	
					Physical Education Elective	1	
						16	

Senior Year

	Fall Semester		*Credits*	*Spring Semester*		*Credits*	
3	**BME 451**	**BME Senior Design I**	3	**BME 452**	**BME Senior Design II**	3	**3**
3		**BME elective D**	3		**BME elective F**	3	**3**
3		**BME elective E**	3		Social Science (not Econ.)	3	
		Science, Technology, Society elective	3		Literature or Creative Writing	3	
		History, Philosophy, or Religion	3		Any approved H&SS course	3	
			15			15	

25 **Minimum Total Credit Hours Required for Graduation = 125** **23**