Description of the Four Majors

INTRODUCTION

Bioengineering/Biomedical Engineering (the terms are overwhelmingly used interchangeably) is perhaps the most rapidly expanding discipline in the USA and world-wide. Popularly it includes almost any mix of engineering and life sciences in any proportion to the point where most engineering programs embrace some form of bioengineering, but Bio/Biomedical engineering programs uniquely provide the depth at the intersection between life sciences and engineering that is expected for the 21st century workforce – industry, medicine, and research.

The UCSD Bioengineering Department has for decades been the national and international leader in bioengineering, establishing the Bioengineering Program, including an undergraduate degree in Bioengineering, in 1966. The department was formed in 1994.

To respond to the greatly expanding opportunities in bioengineering, the UCSD Bioengineering Department has created four distinct concentrations, each recognized as a separate undergraduate major, which makes it possible for us to offer highly focused and effective curricula to the advantage of our students.

The majors are:

Bioengineering: the much evolved version of the original bioengineering degree program (1966) that emphasizes biomechanics and cardiac physiology

Biotechnology: originally emphasizing the chemical/biochemical and sensors aspects of bioengineering it has expanded in response to our increasing ability to design tissues and use molecular biology and genetics to design biological processes, organisms and pharmaceutics

Bioinformatics: the rapidly growing area where smart people, highly informed in genomics, protein production, and metabolic processes, harness the power of computers to model, understand and predict these biological phenomena at the microscale

Biosystems: like all other engineering disciplines, bioengineering involves complex systems – from the micro- and molecular biological to metabolic to physiologic to health and medicine; this major emphasizes the modeling and analytic tools which, accompanied by solid biological/engineering fundamentals, prepare students for futures in medicine and industry

First we give expanded history and explanations of each of our majors. Then we summarize the commonalities – and the differences – in the most dynamic of majors – bioengineering.

OUR MAJORS

Bioengineering: Bioengineering

The redundant title came into being only when the other majors were added. We'll stick with "Bioengineering" for the rest of this document.

In 1966 the UCSD Mechanical Engineering Department included a set of bioengineers with remarkable foresight, not only for world renowned ground breaking research, but also for establishing the basics of education in the field of biomechanics. YC Fung was central to this effort establishing a BS degree in Bioengineering with Mechanical Engineering. In time Marcos Intaglietta, Shu Chien and Gert Schmid-Schonbein, David Gough and others complemented these efforts and grew the program. This degree had not only a decided biomechanics emphasis, but also a strong emphasis on physiology. The help in development from Mechanical Engineering (now the MAE Department) is evident from the strong inclusion of MAE courses in the curriculum.

The development of Bioengineering at UCSD from the Mechanical Engineering Department established a model copied by many other universities. Others developed in parallel but with emphases in electrical engineering (electronics and imaging oriented) and chemical engineering (drug delivery and materials oriented). More recently established or evolving departments include multiple of these themes, with biomechanics as perhaps the most common element.

Biomechanics can be subdivided into

- macro-scale mechanics – e.g. hip and knee implants, sports biomechanics
- tissue mechanics – how do tissues move under stress and deformation and how do they impart force
- fluid mechanics – beginning with the heart and the vascular system
- cellular mechanics – asking how mechanical stresses affect the properties and even growth of cells
- devices – there are a great many biomedical devices with a mechanical component
- mass transfer – how do heat, drugs, etc. move spatially within and without the body

Bioengineering: Biotechnology

This was the second major in the new Bioengineering Department. It was formed because faculty research grew in the area of biosensors, notably for glucose for diabetes monitoring, and the realization that an undergraduate major emphasizing the intersection of biology and chemistry would greatly complement the existing Bioengineering major, and lead to jobs often in the pharmaceutical industry. Subsequently the intellectual areas encompassed by this major grew to include many of the growing molecular biology and cell/tissue oriented applications – in synchrony with the rapid growth of the biotechnology industry worldwide, but especially in California and San Diego.

This major prepares students for careers in the biotechnology industry and for further education in graduate school. The curriculum has a strong engineering foundation with emphasis on biochemical process applications. This program addresses these bioengineering topics:

- biochemistry and metabolism
- biotransport – including how drugs move within the body and cells
- systems biology and kinetics – modeling important biochemical and molecular processes
- bioreactors and bioseparations – how to manufacture biological constructs
- tissue engineering and cellular physiology
- genetic engineering – manipulation of genes to alter cell function and produce biological products
- creation of biosensors for monitoring and disease detection

Education in these areas allows application of bioengineering and physicochemical principles to cellular and molecular biology, with the applications that benefit human health.

Bioengineering: Bioinformatics

Bioinformatics is the study of the structure and flow of information (genetic, metabolic, and regulatory) in living systems. The bioinformatics major emphasizes computation and model-based approaches to assembling, integrating, and interpreting biological information. Students may apply through Bioengineering, Biology and Computer Science; each department’s version of Bioinformatics is customized to the philosophy and requirements of the home department. UCSD’s creation of this major was a first nationally and has served as a model at other universities.

The Bioengineering: Bioinformatics major prepares students for careers in the pharmaceutical, biotechnology, and biomedical software industries, and for further studies in graduate or medical school. The major includes solid training in computer science through data structures. Upper division courses emphasize how to exploit the rapidly growing availability of data bases for genomic, proteomic and other molecular data. The life science base emphasizes the cellular and molecular biology behind the bioinformatics data.

The biotechnology industry finds bioinformatics majors particularly well prepared to complement the laboratory oriented biotechnology trained scientists and engineers. The compelling reason is the ability to make informed predictions, done cheaply with computers, of expensive biomolecular reactions. Bioinformatics majors also have the substantial computer and physiological knowledge to work in the growing field of Biomedical and Health Informatics – exploiting more conventional medical and physiological data.

Bioengineering: Biosystems

"Systems" is a general term used in recognition that in every engineering, biology and even social enterprise is comprised of many interacting parts and that understanding the whole and the parts is highly valuable. Indeed systems biology, as part of biotechnology, captures this idea. The Biosystems major heads in a more conventional engineering direction.

The goal of Biosystems Engineering major is to enable students apply systems engineering to living systems. Engineering is playing an increasing role in physiology and medicine with applications ranging from molecular and cellular characterization of physiological and pathophysiological systems to engineering biomedical devices at scales from nano to macro to systems level measurements and analysis of whole physiology. Students who apply to Bioengineering undergraduate programs are increasingly in demand in biomedicine and hence need to be trained in the precepts of systems engineering. Our goal in this proposed major is to train students for i) a career in biomedical systems engineering, b) research and faculty positions in biosystems engineering with applications across a wide domain of physiology and medicine and c) further degrees in medicine and engineering. The quantitative training this Major offers will be well suited for training the physicians of tomorrow. While we cannot provide you with the entire universe of opportunities within your four years of study, we can give you the basics of both life sciences – emphasizing both physiology and molecular biology – and systems engineering – emphasizing measuring, modeling, designing and predicting the future.

The basic principles of Systems Engineering involve,

Modeling and simulation
Optimization
Systems dynamics
Measurements and Systems Analysis
Statistical Analysis

In order to apply these principles to living systems, the curriculum covers covers living systems, which includes cellular and sub-cellular, tissue and physiological systems analysis; and basic principles of interactions and properties of systems described by mechanical and electrical engineering. Students emerge with very strong analytical skills, useful in a wide range of the "MedTech" and "BioTech" industries. They are well suited to pursue machine learning and other computational approaches to problems in Biomedical and Health Informatics.

OVERVIEW OF THE CURRICULUM FOR ALL BIOENGINEERING MAJORS

We break the curriculum down into these parts:

- preparation as a college graduate with a well-rounded education – your Humanities and Social Science Requirements
- preparation with mathematics and science needed for an Engineering undergraduate degree
- modern biology for engineers
- basic bioengineering coursework common to all bioengineers in the USA
- senior design
- technical electives
- non-curricular opportunities

We separately address

- foci particular to each major that enhance the preparation for a variety of careers

We elaborate on each below, followed by a year by year summary of the curriculum for each major

FOR ALL STUDENTS IN THE BIOENGINEERING DEPARTMENT

Well Rounded Education

At UCSD we have an exceptional and exceptionally strong system of academic and residential colleges. They provide scholarship, identity, camaraderie , etc. We are exceptionally proud that they step up and provide intellectual coherence to the breadth of your curriculum in the social sciences and humanities.

As a footnote we mention that all engineering programs must be accredited by ABET (Accreditation Board for Engineering and Technology) and that ABET demands that all engineering students have a solid liberal arts education. Your colleges exceed what ABET demands.

Never, ever, let someone claim that engineers are not well-rounded. You take more liberal arts courses than liberal arts majors take science and technology courses – and we are in an age where fluency in STEM (science, technology, math, engineering) is essential to being a fully engaged citizen.

Basic Engineering Preparation

There is no substitute for having a fundamental understanding of mathematics, physics, biology and chemistry. All engineers rely on this basic knowledge for their entire careers, long after they have forgotten the equations. There is modest variation by specific major within Bioengineering, as well as between Bioengineering and other engineering majors. The preparation includes calculus (MATH 20ABCDE, 18), physics (PHYS 2ABC and sometimes D) and Chemistry (CHEM 6A, 6B and sometimes more) courses. While we agree less often on which computational courses should be required, it is clear that students, even in the liberal arts, should take as many CSE courses as their time and curriculum permit. Bioengineers are in a sense lucky in that biology is essential and built into the curriculum; some, but not nearly a majority, of universities require beginning biology of their engineering majors. With this solid science background, students are ready to pursue an engineering major.

Beginning Biology in an Engineering Context

Bioengineering students are faced with a daunting task – learning enough basic biology at enough scales and in a very short period of time during their first few years. Most commonly emphasized is a solid sequence that introduces all the major physiological systems. Students emerge with a new vocabulary – they can now discuss most human diseases with accuracy – as well as see how both research and the practice of medicine are organized. Some of our majors place greater emphasis on the cellular and molecular levels, permitting students to be in a great position as regards the breakthroughs in modern biomolecular engineering. Similarly, with their vocabulary and understanding greatly widened, students are ready for upper level courses, work in research labs and even in many summer internships.

We add that the Bioengineering Department teaches these fundamental courses in an "engineering aware" manner – more modeling, more measurements, more computation, more systems thinking. There is a difference between the quantitation that a bioengineer encounters and the qualitative understanding of the life scientist.

Engineering in a Bioengineering Context

Similarly our department teaches engineering fundamentals in a "biology aware" manner – more biological examples and applications of concepts common throughout engineering. Typical are courses in biomechanics, the modeling of chemical and other kinetics, biomaterials, and heat and mass transfer. Quite common is background in biomedical instrumentation including electrical circuits and labororatory ininstrumentation, and biological imaging. Students receive instruction in probability and statistical design that is common throughout all of bioengineering and biomedicine. Computational work varies by major, but finishes with a capstone biocomputation/modeling course. Students emerge with a solid understanding of many of the approaches used by other disciplines but with particular knowledge of the advantages and limitations of application to the biomedical field.

Senior Design for All Bioengineering Majors

The UCSD Bioengineering Senior Design course sequence has the philosophy of "Capstone" design courses, where students use a variety of their previously learned skills to solve a focused engineering problem. The course also serves to meet additional ABET Outcomes and Learning Objectives, including formal design and decision making processes, working in teams, and awareness of ethical and societal consequences.

This course sequence includes two components: BENG 187A/B/C/D, each a 1 credit hour lecture course, taken in the student's last four quarters (Spring/Fall/Winter/Spring); and two 3 credit hour project courses taken in Fall and Winter quarters. The goal of the entire experience is for students to gain experience with a formal design and reporting process, mostly through BENG 187, and to have hands-on experience with engineering design and implementation for biomedical applications through their project courses. They also gain brief introductions to FDA, animal and human subjects, ethics, and presentation skills.

Technical Electives

Eight units of technical electives are required for each major. Some permit four units to be in science, while others require all 8 to be in engineering courses. Independent study, most often in laboratories of Bioengineering faculty, may count as technical electives. Please discuss with UG Advising Staff or faculty.

Curriculum Beyond the Curriculum

A great many Bioengineering students have very greatly enriched their education with experiences outside the classroom and outside the curriculum.

One of the greatest opportunities afforded by universities over the entire USA is the great range of opportunities beyond the classroom. Three simple looks illustrate tremendous sources of opportunities for UCSD bioengineering majors: (a) Bioengineering and related health sciences research opportunities on campus; (b) the Biotech corridor along North Torrey Pines Road; (c) the "mega" industrial complex which is San Diego.

Suggestions include:

BENG 191 – Senior Seminar in Bioengineering – please come! Do not worry about understanding most of the lecture – you should go with the goal of finding out why the lecturer is excited about what s/he does. There are lots of seminars in Bioengineering, other engineering departments and the medical school. Do not be intimidated.

Research Experiences – well over half of our students find opportunities in faculty research labs; many are Bioengineering faculty, but there are also many opportunities in other departments, the UCSD School of Medicine, the Scripps Oceanographic Institute or the Salk Institute. These are enormously valuable.

Other on-campus experiences – some of our students find exceptional experiences in engineering project teams, including Global Ties and Engineering World Health.

Student professional societies provide exceptional opportunities for leadership experience and enhancements to your education. Please check out the BioMedical Engineering Society (BMES), the Engineering in Medicine and Biology Society (EMBS), the International Society for Pharmaceutical Engineering, SynBio, and the Undergraduate Bioinformatics Club.

Internships: many students have found summer jobs or internships which greatly augment their intellectual development. Please contact our internship office for help

Getting a great "beyond the curriculum" experience is part of why you pay tuition. But you have to hustle to take advantage.

COURSE SEQUENCES UNIQUE TO EACH MAJOR

Uniquely Bioengineering

We expect our students to be especially strong in the understanding the mechanics of biological systems from the cellular to tissue to the large physiological system. This is accomplished in an excellent three quarter sequence in Biomechanics (BENG 110, 112A, 112B) including materials at levels ranging from macro (whole or partial body) to tissues to fluids to cellular. Further, students take an intensive laboratory (BENG 172) that emphasizes the biomechanical side of physiology. They cap this with course in Mass Transfer (BENG 103B) and a Biomaterials course (BENG 186A), which helps them understand much better how the materials used for many biomedical applications, such as implants ranging from more traditional knees and hips to state-of-the-art tissues.

Uniquely Biotechnology

Our Biotechnology students spend more time learning basic chemistry than almost all other engineers, getting superp preparation for their transition, during junior on into senior year, as they become Biotechnology majors. They take major coursework in biomolecular science and technology, including hands on laboratory exposure to state of the art technologies for analyzing, identifying and separating biomolecular components, as well as in the growth and genetic manipulation of cells in culture. Lecture work expands their knowledge to the cellular and tissue levels, including interaction with biomaterials, as well as the fundamentals of designing bioreactors used for commercial and research to grow microbial cultures to produce desired protein and other products.

Uniquely Bioinformatics

There are two emphases that distinguish Bioinformatics majors from other Bioengineering majors: much greater and rigorous computer science courses and solid exposure to bioinformatics data bases. The former include not only introductory programming, but also databases and a solid experience in algorithms used in computational inquiries, regardless of application. The latter includes solid courses in how to interrogate biological databases, typically those with genomic and proteomic information. The former prepares students for a wide variety of careers in data science, including medical and non-medical information handling. The latter prepares for careers more directed toward biotechnology industries where computational inquiries complement and often supplant very expensive wet lab experimental investments. Bioinformatics students have a solid base in biology, especially at the cellular and molecular levels.

Uniquely Biosystems

We expect our students to be especially strong in the modeling of biomedical systems. This is already an enormous application area and one that will continue to expand rapidly because of the confluence of the two most rapidly developing technologies on earth, which happen to be the foci of our Biosystems major: systems biology (molecular to physiological) and computational/modeling science. Students in Biosystems are solidly grounded in molecular biology and physiology and then learn much more about computation (BENG 133 Numerical Techniques), signals and modeling (BENG 125 Biocomputational Modeling; BENG 122A Biocontrols; BENG 135 Biosignals; BENG 189 capstone physiological modeling). The overlap of BENG 152 (Lab, instrumentation, physiological signal transduction) and BENG 186B gives students great insight into the revolution in sensing, especially as applied to individuals and expressed as wireless biomedical technology. Students are thoroughly grounded in statistical and probabilistic modeling (including some data mining) through (BENG 133, 134, 135). In all our students are well-grounded in the fundamentals of Systems Engineering: modeling and simulation; optimization; systems dynamics; measurements and systems analysis; and statistical analysis.

YEAR BY YEAR SUMMARY OF THE BIOENGINEERING: BIOENGINEERING MAJOR

(Abbreviated course titles are used. Most courses: 4 units of credit. 1* unit and 2** unit courses are marked.)

First Year

This year is dominated by traditional STEM courses that provide the intellectual ground work for all engineering majors: three terms of calculus (MATH 20A,20B,20C); two terms of Physics (mechanics and electricity and magnetism PHYS 2A,2B, 2BL (lab)); and chemistry (CHEM 6A, 6B). Students take their first life science course (BILD 1) which emphasizes how cells are organized, giving context to both molecular biology and macro physiology courses that follow next year. Finally BENG 1 gives students a hands on experience with bioengineering projects. Students also take Humanities and Social Science Courses that are required of all engineering majors, but customized to the requirements of their residential college.

Fall First Year
Humanities/Social Sciences
Humanities/Social Sciences
MATH 20A Calculus for Engrs I
CHEM 6A General Chemistry I

Winter First Year
Humanities/Social Sciences
MATH 20B Calculus for Engrs II
CHEM 6B General Chemistry II
PHYS 2A Physics Mechanics
BENG 1** Intro Bioengineering

Spring First Year
Humanities/Social Sciences
MATH 20C Calculus/Analytic Geometry
PHYS 2B / 2L** Electricity and Magnetism with Lab*
BILD 1 The Cell

Second Year

This year begins with the completion of foundational engineering courses and the transition to beginning and foundational Bioengineering courses. The math sequence finishes with differential equations (MATH 20D, foundational to circuits), vector calculus (MATH 20E, foundational to biomechanics) and linear algebra (MATH 18, foundational for many computational, modeling, and advanced statistical techniques). PHYS 2C (Fluids, waves, thermodynamics, optics) presages Bioengineering courses in multiple areas. CHEM 7L gives hands on chemistry lab experience. BENG 100 (Statistical Reasoning) provides the basis for a wide range of applications from probabilistic modeling to statistical evaluation of testing data. Most central for biomedical engineers is the BENG 140A/B sequence in physiology – at its simplest, this is what all parents need to know when their child is sick; at heart, however, is basic understanding of the body and how medical practitioners think about the biological basis of most of their profession. Students take three basic but introductory engineering courses: circuits (MAE 140), programming (MAE 8 Matlab), and computer graphical design (MAE 3), which will be complemented in Fall junior year with an experimental lab and more advanced computation. Students emerge well prepared for an intensive junior year in mechanically oriented biomedical engineering. Again, students also take Humanities and Social Science Courses that are required of all engineering majors, but customized to the requirements of their residential college.

Fall Second Year
Humanities/Social Sciences
MATH 20D Differential Equations
Phys 2C / 2L** Fluids, Waves, Optics, Thermo; with Lab
CHEM 7L General Chem Lab

Winter Second Year
Humanities/Social Sciences
MATH 18 Linear Algebra
BENG 140A BioE Physiology I
MAE 40 Linear Circuits
MAE 8 Matlab

Spring Second Year
MAE 3 Graphics
MATH 20E Vector Calculus
BENG 140B BioE Physiology II
BENG 100 Probability & Statistics

Third Year

This year very strongly emphasizes bioengineering courses that expand from fundamental mathematical, engineering and biological foundations to applications found throughout the bioengineering work and research world. As noted above, MAE 107 (Computational Methods) and MAE 170 (Experimental Techniques) give students a solid mechanically oriented background for medical devices and other studies. They take a three term biomechanics sequence: BENG 110/112A/112B (Continuum Mechanics, Tissue Biomechanics and Fluid/Cellular Biomechanics) and complement it with BENG 103B (Mass Transfer). They are now ready for a variety of projects (often in Senior Design) incorporating mechanical design into devices or perhaps modeling the biomechanics of movement or of tissues or fluids. Again, students take Humanities and Social Science Courses that are required of all engineering majors, but customized to the requirements of their residential college. They also begin the senior design sequence described below.

Fall Third Year
Humanities/Social Sciences
BENG 110 Foundation of Biomechanics
MAE 107 Comp. Methods
MAE 170 Exptl Techniques

Winter Third Year
Humanities/Social Sciences
BENG 112A Tissue Biomechanics
BENG 130 BioThermo/Kinetics
BENG 186B BioInstr. Lecture

Spring Third Year
BENG 103B Mass Transfer
BENG 112B Fluid and Cell Biomechanics
BENG 172 BioEng Lab
BENG 187A* Senior Design

Fourth Year

Senior year for Bioengineering majors is dominated by capstone courses. These include the classical Senior Design sequence described elsewhere, but also a Computational Bioengineering course (BENG 125). The Biomaterials course (BENG 186A) rounds out their knowledge of mechanics and materials for a variety of future applications. Students complete two technical electives in addition to the Senior Design project. Again, students take Humanities and Social Science Courses that are required of all engineering majors, but customized to the requirements of their residential college.

Fall Fourth Year
MAE 150 Computer Aided Design
BENG122A Biocontrol
BENG 187B and BENG 1XXA Senior Design

Winter Fourth Year
Humanities/Social Sciences
BENG 187C and BENG 1XXB Senior Design
Technical Elective

Spring Fourth Year
Humanities/Social Sciences
BENG 125 Computational Bioengineering
BENG 186A Biomaterials
BENG 187D* Senior Design
Technical Elective

Note: Humanities/Social Science and Technical Elective courses should be scheduled so as to balance workload and course offerings.

YEAR BY YEAR SUMMARY OF THE BIOENGINEERING: BIOTECHNOLOGY MAJOR

(Abbreviated course titles are used. Most courses: 4 units of credit. 1* unit and 2** unit courses are marked.)

First Year

This year is dominated by traditional STEM courses that provide the intellectual ground work for all engineering majors: three terms of calculus (MATH 20A,20B,20C); two terms of Physics (mechanics and electricity and magnetism PHYS 2A,2B); and chemistry (CHEM 6A, 6B). Biotechnology majors, however, acquire a much stronger chemistry base with CHEM 6C plus lab CHEM 7L). BENG 1 gives students a hands on experience with bioengineering projects. Students also take Humanities and Social Science Courses that are required of all engineering majors, but customized to the requirements of their residential college.

Fall First Year
Humanities/Social Sciences
Humanities/Social Sciences
MATH 20A Calculus for Engrs I
CHEM 6A General Chemistry I

Winter First Year
Humanities/Social Sciences
MATH 20B Calculus for Engrs II
CHEM 6B General Chemistry II
PHYS 2A Physics Mechanics
BENG 1* Intro Bioengineering

Spring First Year
Humanities/Social Sciences
MATH 20C Calculus/Analytic Geometry
PHYS 2B Electricity / Magnetism
CHEM 7L Lab
CHEM 6C General Chemistry III

Second Year

This year continues building the fundamental knowledge needed by Biotechnology majors, especially in the area of organic chemistry (CHEM 40A and 40B). Students finish solid basic sequences in mathematics (differential equations, needed for all engineering disciplines) and linear algebra and vector calculus which provide fundamentals for advanced engineering courses. The math sequence finishes with differential equations (MATH 20D, foundational to much of the next level in all fields of engineering), vector calculus (MATH 20E, foundational to biomechanics and fluids) and linear algebra (MATH 18, foundational for many computational, modeling, and advanced statistical techniques). PHYS 2C (Fluids, waves, thermodynamics, optics) presages multiple Biotechnology courses, as well as a number of other Bioengineering courses. BENG 100 (Statistical Reasoning) provides the basis for a wide range of applications from probabilistic modeling to statistical evaluation of testing data. Students gain essential but beginning programming competence (MAE 8 Matlab). Students emerge well prepared for an intensive junior year in biotechnology courses in the junior year. Again, students also take Humanities and Social Science Courses.

Fall Second Year
Humanities/Social Sciences
MATH 20D Differential Equations
BILD1 The Cell
CHEM 40A Organic Chem I

Winter Second Year
MATH 18 Linear Algebra
Phys 2C / 2L* Fluids, Waves, Optics, Thermo; with Lab
CHEM 40B Organic Chem II

Spring Second Year
MAE 8 Matlab
MATH 20E Vector Calculus
BENG 100 Probability & Statistics

Third Year

Fall of this year completes the basic engineering and science knowledge of the Biotechnology student: fluid mechanics (CENG 101A), hands on sensors/electronics oriented instrumentation lab (MAE 170), and a basic course in genetics (BICD 100). The winter and spring quarters are heavily biotechnology. Students learn in depth about molecular biology and recombinant DNA technologies (BENG 168), as well as the interaction of materials and the body from an engineering perspective. They learn thermodynamics (BENG 130) and mass transfer (BENG 103B) from the point of view of the biological reactions and phenomena. The take the first of two intensive laboratories, BENG 160, where they learn techniques for characterizing and separating biomolecular constituents – cells, protein, nucleic acids. BENG 123 shows use their quantitative understanding of biomolecular/chemical processes to construct computational models that, for instance, product yield in a biochemical system or degree of protein expression. They are now ready for a variety of projects (often in Senior Design) incorporating mechanical design into devices or perhaps modeling the biomechanics of movement or of tissues or fluids. Again, students take Humanities and Social Science Courses. They also begin the senior design sequence described below.

Fall Third Year
Humanities/Social Sciences
CENG 101A Intro Fluid Mech.
BICD 100 Genetics
MAE 170 Exptl Techniques

Winter Third Year
BENG 123 Dynamic Simulation in Bioengineering
BENG 168 Biomolecular Engrg
BENG 130 Biotech Thermo-dynamics and Kinetics

Spring Third Year
Humanities/Social Sciences
BENG 103B Mass Transfer
BENG 160 Chem /Molecular Bioeng Techniques (lab)
BENG 186A Biomaterials
BENG 187A* Senior Design

Fourth Year

Senior year for Biotechnology majors is dominated by advanced biotechnology courses plus capstone courses. Students learn the design of bioreactors, such as are used for growing microbes and harvesting protein products, plus the genetic control of microbial and other systems, followed by product separation and recovery, such as might be used for commercial scaleup of biologically produced products; the Biotechnology Laboratory gives hands on experience with many of the techniques. The Cell and Tissue Engineering course builds on the Biomaterials course from junior year. The capstone courses include the classical Senior Design sequence described elsewhere, but also a Computational Bioengineering course (BENG 125). Students complete two technical electives in addition to the Senior Design project.Students complete their Humanities and Social Science Course requirements.

Fall Fourth Year
BENG 161A Bioreactor Engrg
BENG 162 Biotech Lab
BENG 166A Cell/Tissue Engrg
BENG 187B and BENG 1XXA Senior Design

Winter Fourth Year
Humanities/Social Sciences
BENG 161B Biochemical Engrg
BENG 187C and BENG 1XXB Senior Design
Technical Elective

Spring Fourth Year
Humanities/Social Sciences
BENG 125 Computational Bioengineering
BENG 187D* Senior Design
Technical Elective

Note: Humanities/Social Science and Technical Elective courses should be scheduled so as to balance workload and course offerings.

YEAR BY YEAR SUMMARY OF THE BIOENGINEERING: BIOINFORMATICS MAJOR

(Abbreviated course titles are used. Most courses: 4 units of credit. 1* unit and 2** unit courses are marked.)

First Year

This year is dominated by traditional STEM courses that provide the intellectual ground work for all engineering majors: three terms of calculus (MATH 20A,20B,20C); one term of Physics (mechanics PHYS 2A); and chemistry (CHEM 6A, 6B). Bioinformatics majors, however, acquire a much stronger base in computation as they complete the CSE majors' courses in beginning programming (with Java) and data structures. Students also take Cell Biology (BILD 1) – the cell is the basic biological structure that gives context to the most important genomics and bioinformatics inquiries.. Students also take Humanities and Social Science Courses that are required of all engineering majors, but customized to the requirements of their residential college.

Fall First Year
Humanities/Social Sciences
MATH 20A Calculus for Engrs I
CHEM 6A General Chemistry I
CSE 11 Intro CS / Java

Winter First Year
Humanities/Social Sciences
MATH 20B Calculus for Engrs II
CHEM 6B General Chemistry II
CSE 12 Data Structures / Object Oriented Design
BENG 1* Intro Bioengineering

Spring First Year
Humanities/Social Sciences
MATH 20C Calculus/Analytic Geometry
PHYS 2A Mechanics
BILD 1 The Cell

Second Year

This year has three scientific themes, plus continuation of humanities and social science courses. First is a continuation of the basics underlying much of engineering: MATH 20D, foundational to much of the next level in all fields of engineering), vector calculus (MATH 20E, foundational especially to mechanics and fluids oriented fields), plus PHYS 2B (electricity and magnetism) and PHYS 2C (fluids/waves/optics). Second is development of their sophistication in computer and data handling which will be fundamental to advance bioinformatics study: CSE 100 (advanced data structures), CSE 21 (the math for analyzing algorithms), and BENG 185 (bioinformatics computational laboratory). The third area is the development of biological knowledge emphasizing the identification of structural components at multiple scales: BILD 3 (organismic/evolutionary biology); BENG 102 (the structures within cells and of important biomolecules) and BENG 120 (organic chemistry), and BILD 4 (introductory biology lab).

BENG 100 (Statistical Reasoning) provides the basis for a wide range of applications from probabilistic modeling to statistical evaluation of testing data. Students emerge well prepared for an intensive junior year in Bioinformatics courses in the junior year.

Fall Second Year
Humanities/Social Sciences
MATH 20D Differential Equations
BILD 3 Organism /Evolution Biology
CSE 21 Math for Algorithms and Systems
PHYS 2B Electricity/Magnetism

Winter Second Year
Humanities/Social Sciences
MATH 20E Vector Calculus
Phys 2C Fluids, Waves, Optics, Thermo
BILD 4 Intro Biology Lab
BENG 120 Organic Chem

Spring Second Year
CSE 100 Advanced Data Structures
BIMM 185 Bioinformatics Lab
BENG 102 Cellular/Molecular Structures
BENG 100 Probability & Statistics

Third Year

Bioinformatics students enhance their knowledge base for bioinformatics including genetics (BICD 100) and a molecular biology course focusing on genes and transcription (BIMM 100). They add a second course in handling biological databases (BENG 182). CSE 101 teaches the design of efficient algorithms for applications including bioinformatics data base searching. Again, students take Humanities and Social Science Courses. They also begin the senior design sequence described below.

Fall Third Year
Humanities/Social Sciences
MATH 18 Linear Algebra
CSE 101 Algorithms
BICD 100 Genetics

Winter Third Year
BENG 181 Molecular Sequence Analysis
BENG 130 Biotech Thermo-dynamics and Kinetics
BIMM 100 Molecular Biology

Spring Third Year
Humanities/Social Sciences
BENG 182 Biological Databases
BENG 187A* Senior Design

Fourth Year

Bioinformatics students round out their concentration with three courses. In Applied Genomic Technologies (BENG 183) they learn how DNA, RNA, protein and other biomolecules are extracted from samples. In BENG 168, biomolecular engineering, they learn more of how biomolecules function – including decoding genomes, converting energy, enzymatic activity. In Math they learn how approach probability and statistics in decidedly large but ill-behaved biological systems and data bases. The capstone courses include the classical Senior Design sequence described elsewhere, as well as a Computational Bioengineering course (BENG 125) where students model dynamic non-linear biological systems such as transcriptomes. Students complete two technical electives in addition to the Senior Design project. Students complete their Humanities and Social Science Course requirements.

Fall Fourth Year
Humanities/Social Sciences
BENG 183 Applied Genomic Technologies
BENG 187B and BENG 1XXA Senior Design
Technical Elective

Winter Fourth Year
Humanities/Social Sciences
Math 186 Probability/Statistics for Bioinformatics
BENG 168 Biomolecular Engrg
BENG 187C and BENG 1XXB Senior Design

Spring Fourth Year
Humanities/Social Sciences
BENG 125 Computational Bioengineering
BENG 187D* Senior Design
Technical Elective

Note: Humanities/Social Science and Technical Elective courses should be scheduled so as to balance workload and course offerings.

YEAR BY YEAR SUMMARY OF THE BIOENGINEERING: BIOSYSTEMS MAJOR

(Abbreviated course titles are used. Most courses: 4 units of credit. 1* unit and 2** unit courses are marked.)

First Year

This year is dominated by traditional STEM courses that provide the intellectual ground work for all engineering majors: two terms of calculus (MATH 20A,20B); two terms of Physics (mechanics and electricity and magnetism PHYS 2A,2B, 2BL (lab)); and chemistry (CHEM 6A, 6B). Math 18 (linear algebra) is a prerequisite for the sophomore circuits class (ECE 35). The Biosystems majors take an introductory Matlab programming course (BENG 2) giving students sufficient programming knowledge to use computation in their other UG courses. Finally BENG 1 gives students a hands on experience with bioengineering projects. Students also take Humanities and Social Science Courses that are required of all engineering majors, but customized to the requirements of their residential college.

Fall First Year
Humanities/Social Sciences
MATH 20A Calculus for Engrs I
CHEM 6A General Chemistry I
BENG 2* Intro Program Matlab

Winter First Year
Humanities/Social Sciences
MATH 20B Calculus for Engrs II
CHEM 6B General Chemistry II
PHYS 2A Physics Mechanics
BENG 1** Intro Bioengineering

Spring First Year
Humanities/Social Sciences
MATH 18 Linear Algebra
PHYS 2B / 2L** Electricity and Magnetism with Lab
Humanities/Social Sciences

Second Year

This year begins with the completion of foundational engineering courses and the transition to beginning and foundational Bioengineering courses. The math sequence finishes with differential equations (MATH 20D, foundational to dynamic modeling of biosystems), vector calculus (MATH 20E, foundational biophysical modeling) and linear algebra (MATH 18, foundational for signal processing and high dimensional data). PHYS 2C (Fluids, waves, thermodynamics, optics) presages Bioengineering courses in multiple areas. Special to the Systems majors is ECE 35 (Intro to Analog Design, which is mostly equivalent to the beginning electrical circuits course taken by most engineering majors world wide; see also the discussion of the circuits track importance for Biosystems majors. Biosystems majors also take ECE 45 (Circuits and Systems) which provides their first exposure to the mathematics of systems, and find this reinforced in BENG 100 (Statistical Reasoning) which provides the basis for a wide range of applications from probabilistic modeling to statistical evaluation of testing data. Fundamentals of biological/bioengineering systems appear in BENG 120 (Organic Chemistry, taught from an engineering perspective) and BENG 102 (Molecular Components of Living Systems); these two courses emphasize fundamentals underlying current spectacular advances in molecular biology. Again, students also take Humanities and Social Science Courses that are required of all engineering majors, but customized to the requirements of their residential college.

Fall Second Year
Humanities/Social Sciences
ECE 35 Electrical Circuits
MATH 20C Calculus/Analytic Geometry
Phys 2C / 2L** Fluids, Waves, Optics, Thermo; with Lab

Winter Second Year
Humanities/Social Sciences
ECE 45 Circuits & Systems
MATH 20D Differential Equations
BENG 120 Organic Chemistry

Spring Second Year
Humanities/Social Sciences
MATH 20E Vector Calculus
BENG 102 Molecular Biology
BENG 100 Probability & Statistics

Third Year

This year very strongly emphasizes bioengineering courses that expand from fundamental mathematical and biological foundations to applications found throughout the bioengineering and Biosystems work and research world. Most central for biomedical engineers is the BENG 140A/B sequence in physiology – at its simplest, this is what all parents need to know when their child is sick; at heart, however, is basic understanding of the body and how medical practitioners think about the biological basis of most of their profession. Supporting are the following courses: BENG 110 – how to think about the body as a mechanical system; BENG141 – the use of imaging technologies to discover biomedicine from cells to whole bodies; BENG 130 -- the role of heat and kinetics in biological systems. Biosystems majors increase their competency is experimental and modeling basics and technology with the instrumentation pair (BENG 152 Laboratory dedicated to implementing biosignal acquisition and analysis for Biosystems majors; and BENG 186B Bioinstrumentation lecture course) that dominate physiological biomedical engineering. Biosystems majors also learn in depth about the computational and statistical understanding critical to systems modeling and thinking while taking BENG 133 (Numerical Analysis/Computational Thinking) and BENG 134 (advanced measurements/statistics/probability).

Again, students take Humanities and Social Science Courses that are required of all engineering majors, but customized to the requirements of their residential college. They also begin the senior design sequence described below.

Fall Third Year
Humanities/Social Sciences
BENG 134 Adv Prob/Stat
BENG 141 Biomed Imaging
BENG 110 Continuum Mechanics

Winter Third Year
BENG 140A Physiology I
BENG 130 BioThermo/Kinetics
BENG 186B BioInstr. Lecture
BENG 152 Bioinst/Sys Lab

Spring Third Year
Humanities/Social Sciences
BENG 140B Physiology II
BENG 133 Numerical Techniques
BENG 187A* Senior Design

Fourth Year

Senior year for Biosystems majors is dominated by capstone courses. These include the classical Senior Design sequence described elsewhere, but also a Computational Bioengineering course (BENG 125) and a Physiological Systems Modeling course (BENG 189) that bring together the students' diverse biological knowledge and their mathematical/computational skills.

Again, students take Humanities and Social Science Courses that are required of all engineering majors, but customized to the requirements of their residential college.

Fall Fourth Year
BENG 122A Biocontrol
BENG 135 Bio Signals
BENG 187B and BENG 1XXA Senior Design
BENG Technical Elective

Winter Fourth Year
Humanities/Social Sciences
Humanities/Social Sciences
BENG 187C and BENG 1XXB Senior Design
BENG Technical Elective

Spring Fourth Year
Humanities/Social Sciences
BENG 125 Computational Bioengineering
BENG 189 Physiological Systems Engineering
BENG 187D* Senior Design