SCHOOL OF ENGINEERING

BIOENGINEERING

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Courses offered by the Department of Bioengineering are listed under the subject code BIOE on the *Stanford Bulletin's* ExploreCourses web site.

The mission of the Department of Bioengineering is to create a fusion of engineering and the life sciences that promotes scientific discovery and the invention of new technologies and therapies through research and education. The department encompasses both the use of biology as a new engineering paradigm and the application of engineering principles to medical problems and biological systems. The discipline embraces biology as a new science base for engineering.

Bioengineering is jointly supported by the School of Engineering and the School of Medicine. The facilities and personnel of the Department of Bioengineering are housed in the James H. Clark Center, the William F. Durand Building for Space Engineering and Science, the William M. Keck Science Building, the Jerry Yang and Akiko Yamazaki Environment and Energy Building, and the Richard M. Lucas Center for Magnetic Resonance Spectroscopy and Imaging.

The departmental headquarters is located in the James H. Clark Center for Biomedical Engineering and Sciences, along with approximately 600 faculty, staff, and students from more than 40 University departments. The Clark Center is also home to Stanford's Bio-X program, a collaboration of the Schools of Engineering, Medicine, Humanities and Sciences, and Earth Sciences.

Courses in the teaching program lead to the degrees of Master of Science and Doctor of Philosophy. The department collaborates in research and teaching programs with faculty members in Chemical Engineering, Mechanical Engineering, Electrical Engineering, and departments in the School of Medicine. Quantitative biology is the core science base of the department. The research and educational thrusts are in biomedical computation, biomedical imaging, biomedical devices, regenerative medicine, and cell/molecular engineering. The clinical dimension of the department includes cardiovascular medicine, neuroscience, orthopedics, cancer care, neurology, and environment.

UNDERGRADUATE PROGRAMS IN BIOENGINEERING

Although primarily a graduate-level department, pre-approved B.S. majors in Bioengineering, Biomechanical Engineering and Biomedical Computation can be arranged through the School of Engineering. For detailed information, see the "School of Engineering" section of this bulletin and the *Handbook for Undergraduate Engineering Programs* at http://ughb.stanford.edu and available from the Office of the Dean of Engineering.

GRADUATE PROGRAMS IN BIOENGINEERING

The University's requirements for the M.S. and Ph.D. degrees are outlined in the "Graduate Degrees" section of this bulletin.

Admission—Students are expected to enter with a series of core competencies in mathematics, biology, chemistry, physics, computing, and engineering. Students entering the program are assessed by the examination of their undergraduate transcripts and research experiences. Specifically, we require that students have completed mathematics through multivariable calculus and differential equations, completed a series of undergraduate biology courses (equivalent to BIO 41,42,43 series) and completed physics, chemistry, and computer sciences courses required of all undergraduate majors in engineering.

Qualified applicants are encouraged to apply for predoctoral national competitive fellowships, especially those from the National Science Foundation. Applicants to the Ph.D. program should consult with their financial aid officers for information and applications.

The deadline for receiving applications is December 1, 2009.

Further information and application forms for all graduate degree programs may be obtained from Graduate Admissions, the Registrar's Office, http://gradadmissions.stanford.edu.

COTERMINAL B.S./M.S. PROGRAM IN BIOENGINEERING

This option is available to outstanding Stanford undergraduates who wish to work simultaneously toward a B.S. in another field and an M.S. in Bioengineering. The degrees may be granted simultaneously or at the conclusion of different quarters, though the bachelor's degree cannot be awarded after the master's degree has been granted. As Bioengineering does not currently offer an undergraduate program, the B.S. degree must be from another department. The University minimum requirements for the coterminal bachelor's/master's program are 180 units for the bachelor's degree plus 45 unduplicated units for the master's degree. Students may apply for the coterminal B.S. and M.S. program after 120 units are completed and they must be accepted into our program one quarter before receiving the B.S. degree. Students should apply directly to the Bioengineering Student Service Office by December 1, 2009. We require students interested in our coterminal degree to take the Graduate Record Examination (GRE); applications may be obtained at http://www.gre.org. New coterminal applications and procedures are now available on the Office of the University Registrar web site. Access the new application form, instructions, and supporting documents online at http://bioengineering.stanford.edu/education/coterminal.html; University regulations and forms concerning coterminal degree programs are available at http://registrar.stanford.edu/shared/publications.htm#Coterm.

The application must provide evidence of potential for strong academic performance as a graduate student. The application is evaluated and acted upon by the graduate admissions committee of the department. Students are expected to enter with a series of core competencies in mathematics, biology, chemistry, physics, computing, and engineering. Typically, a GPA of at least 3.5 in engineering, science, and math is expected.

MASTER OF SCIENCE IN BIOENGINEERING

The Master of Science in Bioengineering requires 45 units of course work. The curriculum consists of core bioengineering courses, technical electives, seminars and unrestricted electives. Core courses focus on quantitative biology and biological systems analysis. Approved technical electives are chosen by the student in consultation with his/her graduate adviser, and can be selected from graduate course offerings in mathematics, statistics, engineering, physical sciences, life sciences, and medicine. Seminars highlight emerging research in bioengineering and provide training in research ethics. Unrestricted electives can be freely chosen by the student in association with his/her adviser.

The department's requirements for the M.S. in Bioengineering are:

1. *Core Bioengineering courses* (9 units); the following courses are required:
   BIOE 300A. Molecular and Cellular Bioengineering
   BIOE 300B. Physiology and Tissue Engineering
   BIOE 301A. Molecular and Cellular Bioengineering Lab
   BIOE 301B. Clinical Needs and Technology
   These courses, together with the approved technical electives, should form a cohesive course of study that provides depth and breadth.
2. *Approved Technical Electives* (27 units): these units must be selected from graduate courses in mathematics, statistics, engineering, physical science, life science, and medicine. They should be chosen in concert with the bioengineering courses to provide a cohesive degree program in a bioengineering focus area. Students are required to take at least one course in some area of device or instrumentation. Up to 9 units of directed study and research may be used as approved electives.
3. *Seminars* (3 units): the seminar units should be fulfilled through BIOE 390, Introduction to Bioengineering Research, BIOE 393, Bioengineering Departmental Research Colloquium, or BIOE 459, Frontiers in Interdisciplinary Biosciences. Other relevant seminar units may also be used with the approval of the faculty adviser. One of the seminar units must be MED 255, The Responsible Conduct of Research.
4. *Unrestricted Electives* (6 units).

Students are assigned an initial faculty adviser to assist them in designing a plan of study that creates a cohesive degree program with a concentration in a particular bioengineering focus area. These focus areas include, but are not limited to: Biomedical Computation, Regenerative Medicine/Tissue Engineering, Molecular and Cell Bioengineering, Biomedical Imaging, and Biomedical Devices.

To ensure that an appropriate program is pursued by all M.S. candidates, students who first matriculate at Stanford at the graduate level (a) submit an adviser-approved Program Proposal for a Master's Degree form to the student services office during the first month of the first quarter of enrollment and (b) obtain approval from the M.S. adviser and the Chair of Graduate Studies for any subsequent program change or changes. It is expected that the requirements for the M.S. in Bioengineering can be completed within approximately one year. There is no thesis requirement for the M.S.

Due to the interdisciplinary nature of Bioengineering; a number of courses are offered directly through the Bioengineering Department, but many are available through other departments. See respective department listings for course descriptions.

COGNATE COURSES

BIOC 218. Computational Molecular Biology (Same as BIOMEDIN 231)
BIOMEDIN 210. Modeling Biomedical Systems: Ontology, Terminology, Problem Solving (Same as CS 270)
BIOMEDIN 217. Translational Bioinformatics (Same as CS 275)
CHEMENG 450. Advances in Biotechnology
EE 369A,B. Medical Imaging Systems I,II
EE 369C. Medical Image Reconstruction
ME 280. Skeletal Development and Evolution
ME 287. Soft Tissue Mechanics
ME 381. Orthopaedic Bioengineering
ME 382A,B. Medical Device Design
RAD 226. In Vivo Magnetic Resonance Spectroscopy and Imaging

DOCTOR OF PHILOSOPHY IN BIOENGINEERING

A student studying for the Ph.D. degree must complete a master's degree (45 units) comparable to that of the Stanford M.S. degree in Bioengineering. Up to 45 units of master's degree residency units may be counted towards the degree. The Ph.D. degree is awarded after the completion of a minimum of 135 units of graduate work as well as satisfactory completion of any additional University requirements. Students admitted to the Ph.D. program with an M.S. degree must complete at least 90 units of work at Stanford. The maximum number of transfer units is 45.

On the basis of the research interests expressed in their application, students are assigned an initial faculty adviser who assists them in choosing courses and identifying research opportunities. The department does not require formal lab rotations, but students are encouraged to explore research activities in two or three labs during their first academic year.

Prior to being formally admitted to candidacy for the Ph.D. degree, the student must demonstrate knowledge of bioengineering fundamentals and a potential for research by passing a qualifying oral examination.

Typically, the exam is taken shortly after the student earns a master's degree. The student is expected to have a nominal graduate Stanford GPA of 3.25 to be eligible for the exam. Once the student's faculty sponsor has agreed that the exam is to take place, the student must submit an application folder containing items including a curriculum vitae, research project abstract, and preliminary dissertation proposal to the student services office. Information about the exam may be obtained from the student services office.

In addition to the course requirements of the M.S. degree, doctoral candidates must complete a minimum of 15 additional units of approved formal course work (excluding research, directed study, and seminars).

Dissertation Reading Committee—Each Ph.D. candidate is required to establish a reading committee for the doctoral dissertation within six months after passing the department's Ph.D. qualifying exams. Thereafter, the student should consult frequently with all members of the committee about the direction and progress of the dissertation research.

A dissertation reading committee consists of the principal dissertation adviser and at least two other readers. Reading committees in Bioengineering may include faculty from another department. It is expected that at least one member of the Bioengineering faculty be on each reading committee. The initial committee, and any subsequent changes, must be officially approved by the department Chair.

University Oral and Dissertation—The Ph.D. candidate is required to take the University oral examination after the dissertation is substantially completed (with the dissertation draft in writing), but before final approval. The examination consists of a public presentation of dissertation research, followed by substantive private questioning on the dissertation and related fields by the University oral committee (four selected faculty members, plus a chair from another department). Once the oral has been passed, the student finalizes the dissertation for reading committee review and final approval. Forms for the University oral scheduling and a one-page dissertation abstract should be submitted to the department student services office at least three weeks prior to the date of the oral for departmental review and approval.

PH.D. MINOR IN BIOENGINEERING

Doctoral students pursuing a Ph.D. degree in a major other than Bioengineering may apply for the Ph.D. minor in Bioengineering. A minor is a not a requirement for any degree, but is available when agreed upon by the student and the major and minor department.

Application forms, including the University's general requirements, can be found at http://registrar.stanford.edu/shared/forms.htm.

A student desiring a Ph.D. minor in Bioengineering must have a minor program advisor who is a regular Bioengineering faculty member. This advisor must be a member of the student's reading committee for the doctoral dissertation, and the entire reading committee must meet at least one year prior to the date of the student's dissertation defense.

The Ph.D. minor program must include at least 20 units of course work in Stanford Bioengineering or Bioengineering cognate courses at or above the 200 level. Of these 20 units, no more than 10 can be in cognate courses. All courses listed to fulfill the 20-unit requirement must be taken for a letter grade and the GPA must be at least 3.25. Courses used for a minor may not be used to also meet the requirements for a master's degree.

M.D./PH.D. DUAL DEGREE PROGRAM

Students interested in a career oriented towards bioengineering and medicine can pursue the combined M.D./Ph.D. degree program. Stanford has two ways to do an M.D./Ph.D. U.S. citizens and permanent residents can apply to the Medical Scientist Training Program and can be accepted with funding from both M.D. and Ph.D. programs for stipend and tuition. They can then select a bioengineering laboratory for their Ph.D. Students not admitted to the Medical Scientist Training Program must apply to be admitted separately to the M.D. program and the Ph.D. program of their choice.

The Ph.D. is administered by the Department of Bioengineering. To be formally admitted as a Ph.D. degree candidate in this combined degree program, the student must apply through normal departmental channels and must have earned or have plans to earn an M.S. in bioengineering or other engineering discipline at Stanford or another university. The M.S. requires 45 units of course work which consists of core bioengineering courses, technical electives, seminars, and 6 unrestricted units. Students must also pass the Department of Bioengineering Ph.D. qualifying examination.

For students fulfilling the full M.D. requirements who earned their master's level engineering degree at Stanford, the Department of Bioengineering waives the normal departmental requirement of 15 units applied towards the Ph.D. degree beyond the master's degree level through formal course work. Consistent with the University Ph.D. requirements, the department accepts 15 units comprised of courses, research, or seminars approved by the student's academic adviser and the department chair. Students not completing their M.S. engineering degree at Stanford are required to take 15 units of formal course work in engineering-related areas as determined by their academic adviser.

JOINT DEGREE PROGRAMS IN BIOENGINEERING AND THE SCHOOL OF LAW

The School of Law and the Department of Bioengineering offer joint programs leading to either a J.D. degree combined with an M.S. degree in Bioengineering or to a J.D. degree combined with a Ph.D. in Bioengineering.

The J.D./M.S. and J.D./Ph.D. degree programs are designed for students who wish to prepare themselves intensively for careers in areas relating to both law and bioengineering. Students interested in either joint degree program must apply and gain entrance separately to the School of Law and the Department of Bioengineering and, as an additional step, must secure permission from both academic units to pursue degrees in those units as part of a joint degree program. Interest in either joint degree program should be noted on the student's admission applications and may be considered by the admission committee of each program. Alternatively, an enrolled student in either the Law School or the Bioengineering Department may apply for admission to the other program and for joint degree status in both academic units after commencing study in either program.

Joint degree students may elect to begin their course of study in either the School of Law or the Department of Bioengineering. Faculty advisers from each academic unit will participate in the planning and supervising of the student's joint program. Students must be enrolled full time in the Law School for the first year of law school, and, at some point during the joint program, may be required to devote one or more quarters largely or exclusively to studies in the Bioengineering program regardless of whether enrollment at that time is in the Law School or in the Department of Bioengineering. At all other times, enrollment may be in the graduate school or the Law School, and students may choose courses from either program regardless of where enrolled. Students must satisfy the requirements for both the J.D. and the M.S. or Ph.D. degrees as specified in the *Stanford Bulletin* or elsewhere.

The Law School shall approve courses from the Bioengineering Department that may count toward the J.D. degree, and the Bioengineering Department shall approve courses from the Law School that may count toward the M.S. or Ph.D. degree in Bioengineering. In either case, approval may consist of a list applicable to all joint degree students or may be tailored to each individual student's program. The lists may differ depending on whether the student is pursuing an M.S. or a Ph.D. in Bioengineering.

In the case of a J.D./M.S. program, no more than 45 units of approved courses may be counted toward both degrees. In the case of a J.D./Ph.D. program, no more than 54 units of approved courses may be counted toward both degrees. In either case, no more than 36 units of courses that originate outside the Law School may count toward the law degree. To the extent that courses under this joint degree program originate outside of the Law School but count toward the law degree, the law school credits permitted under Section 17(1) of the Law School Regulations shall be reduced on a unit-per-unit basis, but not below zero. The maximum number of law school credits that may be counted toward the M.S. or Ph.D. in Bioengineering is the greater of: (i) 15 units; or (ii) the maximum number of units from courses outside of the department that M.S. or Ph.D. candidates in Bioengineering are permitted to count toward the applicable degree under general departmental guidelines or in the case of a particular student's individual program. Tuition and financial aid arrangements will normally be through the school in which the student is then enrolled.

BIOENGINEERING (BIOE)

UNDERGRADUATE COURSES IN BIOENGINEERING

BIOE 41. Physical Biology of Macromolecules
Principles of statistical physics and thermodynamics, with applications to molecular biology. Topics include entropy, temperature, free energy, chemical forces, self assembly, cooperative transitions in macromolecules, enzyme kinetics, molecular machines, and an introduction to genomic and proteomic technologies. Corequisite: BIO 41.
4 units, Aut (Quake, S)

BIOE 42. Physical Biology of Cells
Principles of transport, continuum mechanics, and fluids, with applications to cell biology. Topics include random walks, diffusion, Langevin dynamics, transport theory, low Reynolds number flow, and beam theory, with applications including quantitative models of protein trafficking in the cell, mechanics of the cell cytoskeleton, the effects of molecular noise in development, the electromagnetics of nerve impulses, and an introduction to cardiovascular fluid flow. Concurrent enrollment in BIO 42 is required.
4 units, Win (Huang, K)

BIOE 44. Synthetic Biology Lab
Introduction to next-generation techniques in genetic, molecular, biochemical, and cellular engineering. Lab modules build upon current research including: gene and genome engineering via decoupled design and construction of genetic material; component engineering focusing on molecular design and quantitative analysis of experiments; device and system engineering using abstracted genetically encoded objects; and product development based on useful applications of biological technologies. Limited enrollment. Priority given to majors.
4 units, Spr (Staff)

BIOE 70Q. Medical Device Innovation
(S,Sem) Stanford Introductory Seminar. Preference to sophomores. Commonly used medical devices in different medical specialties. Guest lecturers include Stanford Medical School physicians, entrepreneurs, and venture capitalists. How to identify clinical needs and design device solutions to address these needs. Fundamentals of starting a company. Field trips to local medical device companies; workshops. No previous engineering training required.
3 units, Spr (Staff)

BIOE 80. Introduction to Bioengineering
(Same as ENGR 80) Overview of biological engineering focused on engineering analysis and design of biological processes. Topics include overall material and energy balances, rates of biochemical reactions and processes, genetic programming of biological systems, links between information and function, and technologies to probe and manipulate biological systems. Applications of these concepts to areas of current technological importance, including biotechnology, biosynthesis, molecular/cellular therapeutics, and personalized medicine and gene therapy. GER:DB-EngrAppSci
3 units, Spr (Scott, M; Smolke, C)

BIOE 144. Lectures and Dialogue on Synthetic Biology
New foundational tools that are making biology easier to engineer. Topics include DNA synthesis, RNA, protein, and cellular engineering, programmed pattern formation, standardization, and abstraction. Current and future applications of biotechnology. Social issues such as ethics, safety, security, and ownership, sharing, and innovation frameworks. All majors welcome; optional weekly background tutorial.
3 units, Win (Endy, A)

BIOE 191. Bioengineering Problems and Experimental Investigation
Directed study and research for undergraduates on a subject of mutual interest to student and instructor. Prerequisites: consent of instructor and adviser.
1-5 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

GRADUATE COURSES IN BIOENGINEERING

BIOE 212. Introduction to Biomedical Informatics Research Methodology
(Same as BIOMEDIN 212, CS 272, GENE 212) Hands-on software building. Student teams conceive, design, specify, implement, evaluate, and report on a software project in the domain of biomedicine. Creating written proposals, peer review, providing status reports, and preparing final reports. Guest lectures from professional biomedical informatics systems builders on issues related to the process of project management. Software engineering basics. Prerequisites: BIOMEDIN 210, 211, 214, 217 or consent of instructor.
3 units, Aut (Altman, R; Cheng, B; Klein, T)

BIOE 214. Representations and Algorithms for Computational Molecular Biology
(Same as BIOMEDIN 214, CS 274, GENE 214) Topics: introduction to bioinformatics and computational biology, algorithms for alignment of biological sequences and structures, computing with strings, phylogenetic tree construction, hidden Markov models, Gibbs Sampling, basic structural computations on proteins, protein structure prediction, protein threading techniques, homology modeling, molecular dynamics and energy minimization, statistical analysis of 3D biological data, integration of data sources, knowledge representation and controlled terminologies for molecular biology, microarray analysis, machine learning (clustering and classification), and natural language text processing. Prerequisites: programming skills; consent of instructor for 3 units.
3-4 units, Spr (Staff)

BIOE 220. Imaging Anatomy
(Same as RAD 220) The physics of medical imaging and human anatomy through medical images. Emphasis is on normal anatomy, contrast mechanisms, and the relative strengths of each imaging modality. Labs reinforce imaging techniques and anatomy. Prerequisites: basic biology, physics.
3 units, Win (Pauly, K; Gold, G)

BIOE 222A. Multimodality Molecular Imaging in Living Subjects
(Same as RAD 222A) Focuses on instruments and chemistries for imaging of cellular and molecular processes in vivo. Basics of instrumentation physics, chemistry of molecular imaging probes, and an introduction to preclinical and clinical molecular imaging modalities.
4 units, Aut (Contag, C; Xing, L; Rao, J)

BIOE 222B. Chemistry of Molecular Probes for Imaging in Living Subjects
(Same as RAD 222B) Focuses on molecular probes that target specific disease mechanisms. The ideal characteristics of molecular probes; how to optimize their design for use as effective imaging reagents that target specific steps in biological pathways and reveal the nature of disease through noninvasive assays.
4 units, Win (Contag, C; Rao, J; Xing, L)

BIOE 222C. Topics in Multimodality Imaging in Living Subjects
(Same as RAD 222C) Focuses on emerging chemistries and instruments that address unmet needs for improved diagnosis and disease management in cancer, neurological disease, cardiovascular medicine and musculoskeletal disorders. Objective is to identify problems or controversies in the field, and to resolve them through understanding the relevant primary literature.
4 units, Spr (Contag, C; Xing, L; Rao, J)

BIOE 261. Principles and Practice of Stem Cell Engineering
(Same as NSUR 261) Quantitative models used to characterize incorporation of new cells into existing tissues emphasizing pluripotent cells such as embryonic and neural stem cells. Molecular methods to control stem cell decisions to self-renew, differentiate, die, or become quiescent. Practical, industrial, and ethical aspects of stem cell technology application. Final projects: team-reviewed grants and business proposals.
3 units, alternate years, not given this year

BIOE 280. Skeletal Development and Evolution
(Same as ME 280) The mechanobiology of skeletal growth, adaptation, regeneration, and aging is considered from developmental and evolutionary perspectives. Emphasis is on the interactions between mechanical and chemical factors in the regulation of connective tissue biology. Prerequisites: 80, or Human Biology core, or Biological Sciences core.
3 units, Spr (Carter, D)

BIOE 280. Skeletal Development and Evolution
(Same as ME 280) The mechanobiology of skeletal growth, adaptation, regeneration, and aging is considered from developmental and evolutionary perspectives. Emphasis is on the interactions between mechanical and chemical factors in the regulation of connective tissue biology. Prerequisites: 80, or Human Biology core, or Biological Sciences core.
3 units, Spr (Carter, D)

BIOE 281. Biomechanics of Movement
(Same as ME 281) Experimental techniques to study human and animal movement including motion capture systems, EMG, force plates, medical imaging, and animation. The mechanical properties of muscle and tendon, and quantitative analysis of musculoskeletal geometry. Projects and demonstrations emphasize applications of mechanics in sports, orthopedics, and rehabilitation.
3 units, Win (Delp, S)

BIOE 282. Performance, Development, and Adaptation of Skeletal Muscle
Fundamentals of skeletal muscle by study of classical and recent research articles. Emphasis on the interactions between mechanics, biology, and electrophysiology in skeletal muscle performance, development, adaptation, control, and disease. Lab activities explore research methods discussed in class. Limited Enrollment. Prerequisites: engineering or biology core coursework.
3 units, Aut (Delp, S)

BIOE 284A. Cardiovascular Bioengineering
(Same as ME 284A) Bioengineering principles applied to the cardiovascular system. Anatomy of human cardiovascular system, comparative anatomy, and allometric scaling principles. Cardiovascular molecular and cell biology. Overview of continuum mechanics. Form and function of blood, blood vessels, and the heart from an engineering perspective. Normal, diseased, and engineered replacement tissues.
3 units, Aut (Taylor, C)

BIOE 284B. Cardiovascular Bioengineering
(Same as ME 284B) Continuation of ME 284A. Integrative cardiovascular physiology, blood fluid mechanics, and transport in the microcirculation. Sensing, feedback, and control of the circulation. Overview of congenital and adult cardiovascular disease, diagnostic methods, and treatment strategies. Engineering principles to evaluate the performance of cardiovascular devices and the efficacy of treatment strategies.
3 units, Win (Taylor, C)

BIOE 291. Principles and Practice of Optogenetics for Optical Control of Biological Tissues
Principles and practice of optical control of biological processes (optogenetics), emphasizing bioengineering approaches. Theoretical, historical, and current practice of the field. Requisite molecular-genetic, optoelectronic, behavioral, clinical, and ethical concepts, and mentored analysis and presentation of relevant papers. Final projects of research proposals and a laboratory component in BioX to provide hands-on training. Contact instructor before registering.
3 units, Aut (Deisseroth, K)

BIOE 300A. Molecular and Cellular Bioengineering
The molecular and cellular bases of life from an engineering perspective. Analysis and engineering of biomolecular structure and dynamics, enzyme function, molecular interactions, metabolic pathways, signal transduction, and cellular mechanics. Quantitative primary literature. Prerequisites: CHEM 171 and BIO 41 or equivalents; MATLAB or an equivalent programming language.
3 units, Aut (Bryant, Z)

BIOE 300B. Physiology and Tissue Engineering
The interaction, communication, and disorders of major organ systems and relevant developmental biology and tissue engineering from cells to complex organs.
3 units, Win (Deisseroth, K; Covert, M)

BIOE 301A. Molecular and Cellular Engineering Lab
Preference to Bioengineering graduate students. Practical applications of biotechnology and molecular bioengineering including recombinant DNA techniques, molecular cloning, microbial cell growth and manipulation, library screening, and microarrays. Emphasis is on experimental design and data analysis. Limited enrollment. Corequisite: 300A.
2 units, Aut (Cochran, J)

BIOE 301B. Clinical Needs and Technology
Diagnostic and therapeutic methods in medicine. Labs include a pathology/histology session, pulmonary function testing, and the Goodman Simulation Center. Each student paired with a physician for observation of an operation or procedure. Limited enrollment. Corequisite: 300B.
1 unit, Win (Feinstein, J)

BIOE 301C. Diagnostic Imaging Lab
Biomedical instruments and diagnostic devices. Emphasis is on comparing measurements with theoretical predictions. Labs include ECG, MRI, microfluidics, CT, and EEG. Prerequisites: 300B and 301B.
2 units, Spr (Boahen, K)

BIOE 310. Systems Biology
(Same as BIOC 278, CS 278, CSB 278) Complex biological behaviors through the integration of computational modeling and molecular biology. Topics: reconstructing biological networks from high-throughput data and knowledge bases. Network properties. Computational modeling of network behaviors at the small and large scale. Using model predictions to guide an experimental program. Robustness, noise, and cellular variation. Prerequisites: background in biology and mathematical analysis.
3 units, not given this year

BIOE 331. Protein Engineering
The design and engineering of biomolecules emphasizing proteins, antibodies, and enzymes. Combinatorial methodologies, rational design, protein structure and function, and biophysical analyses of modified biomolecules. Clinically relevant examples from the literature and biotech industry. Prerequisite: basic biochemistry.
3 units, alternate years, not given this year

BIOE 332. Large-Scale Neural Modeling
Emphasis is on modeling neural systems at the circuit level, ranging from feature maps in neocortex to episodic memory in hippocampus. Simulation exercises to explore the roles of cellular properties, synaptic plasticity, spike synchrony, rhythmic activity, recurrent connectivity, and noise and heterogeneity; quantitative techniques to analyze and predict network behavior. Work in teams of two; run simulations in real-time on neuromorphic hardware developed for this purpose.
3 units, Win (Boahen, K)

BIOE 333. Interfacial Phenomena and Bionanotechnology
Fundamental and applied study of interfacial phenomena and effects of surface-active molecules on behavior of important biological, biochemical, environmental, and bioengineering systems. Discussion of central mathematical equations in surface science attributed to Laplace, Gibbs, Kelvin, and Young. Self-assembly of surfactants and biomolecules. Relevance of interfacial phenomena to protein folding/unfolding and microfluidics. Applications to recent research advances in bionano- and biomicrotechnology, using scientific literature.
3 units, Spr (Barron, A)

BIOE 334. Engineering Principles in Molecular Biology
The achievements and difficulties that exemplify the interface of theory and quantitative experiment. Topics include: bistability, cooperativity, robust adaptation, kinetic proofreading, analysis of fluctuations, sequence analysis, clustering, phylogenetics, maximum likelihood methods, and information theory. Sources include classic papers.
3 units, not given this year

BIOE 335. Molecular Motors I
Physical mechanisms of mechanochemical coupling in biological molecular motors, using F1 ATPase as the major model system. Applications of biochemistry, structure determination, single molecule tracking and manipulation, protein engineering, and computational techniques to the study of molecular motors.
3 units, alternate years, not given this year

BIOE 341. Computational Neural Networks
Distributed neural network implementations of algorithms for signal processing, function approximation, and control. Representation of information in networks of spiking neurons. Supervised and unsupervised learning algorithms. Radial basis functions, principal and independent components analysis, reinforcement learning, support-vector machines, self-organizing maps, auto-associative learning, hidden Markov models. Related methods from information theory, signal processing, bayesian estimation, and stochastic systems. Final project in software or programmable hardware. Prerequisites: linear algebra, dynamic systems, and probability theory as in MATH 103, EE 102A, and EE 178 or equivalent, and programming experience in C++ or Matlab.
3 units, not given this year

BIOE 355. Advanced Biochemical Engineering
(Same as CHEMENG 355) Combines biological knowledge and methods with quantitative engineering principles. Quantitative review of biochemistry and metabolism; recombinant DNA technology and synthetic biology (metabolic engineering). The production of protein pharmaceuticals as a paradigm for the application of chemical engineering principles to advanced process development within the framework of current business and regulatory requirements. Prerequisite: CHEMENG 181 (formerly 188) or BIOSCI 41, or equivalent.
3 units, Win (Swartz, J)

BIOE 361. Biomaterials in Regenerative Medicine
(Same as MATSCI 381) Materials design and engineering for regenerative medicine. How materials interact with cells through their micro- and nanostructure, mechanical properties, degradation characteristics, surface chemistry, and biochemistry. Examples include novel materials for drug and gene delivery, materials for stem cell proliferation and differentiation, and tissue engineering scaffolds. Prerequisites: undergraduate chemistry, and cell/molecular biology or biochemistry.
3 units, Win (Heilshorn, S; Cochran, J), alternate years, not given next year

BIOE 370. Microfluidic Device Laboratory
Fabrication of microfluidic devices for biological applications. Photolithography, soft lithography, and micromechanical valves and pumps. Emphasis is on device design, fabrication, and testing.
2 units, Win (Quake, S; Melin, J)

BIOE 374A. Biodesign Innovation Core: Needs Finding and Concept Creation
(Same as ME 368A, MED 272A) Two quarter sequence. Inventing new medical devices and instrumentation, including: methods of validating medical needs; techniques for analyzing intellectual property; basics of regulatory (FDA) and reimbursement planning; brainstorming and early prototyping. Guest lecturers and practical demonstrations. May be taken alone (2 units) or in combination with the project component (4 units).
2-4 units, Win (Yock, P; Zenios, S; Milroy, J; Brinton, T)

BIOE 374B. Biodesign Innovation Core: Concept Development and Implementation
(Same as ME 368B, MED 272B) Two quarter sequence. How to take a medical device invention forward from early concept to technology translation and development. Topics include prototyping; patent strategies; advanced planning for reimbursement and FDA approval; choosing translation route (licensing versus start-up); ethical issues including conflict of interest; fundraising approaches and cash requirements; essentials of writing a business or research plan; strategies for assembling a development team. May be taken alone (2 units) or in combination with the project component (4 units). Prerequisite: MED 272A, ME368A, or BIOE 374A.
2-4 units, Spr (Staff)

BIOE 381. Orthopaedic Bioengineering
(Same as ME 381) Engineering approaches applied to the musculoskeletal system in the context of surgical and medical care. Fundamental anatomy and physiology. Material and structural characteristics of hard and soft connective tissues and organ systems, and the role of mechanics in normal development and pathogenesis. Engineering methods used in the evaluation and planning of orthopaedic procedures, surgery, and devices.
3 units, Aut (Carter, D)

BIOE 381. Orthopaedic Bioengineering
(Same as ME 381) Engineering approaches applied to the musculoskeletal system in the context of surgical and medical care. Fundamental anatomy and physiology. Material and structural characteristics of hard and soft connective tissues and organ systems, and the role of mechanics in normal development and pathogenesis. Engineering methods used in the evaluation and planning of orthopaedic procedures, surgery, and devices.
3 units, Aut (Carter, D)

BIOE 386. Neuromuscular Biomechanics
(Same as ME 386) The interplay between mechanics and neural control of movement. State of the art assessment through a review of classic and recent journal articles. Emphasis is on the application of dynamics and control to the design of assistive technology for persons with movement disorders.
3 units, not given this year

BIOE 390. Introduction to Bioengineering Research
(Same as MED 289) Preference to medical and bioengineering graduate students. Bioengineering is an interdisciplinary field that leverages the disciplines of biology, medicine, and engineering to understand living systems, and engineer biological systems and improve engineering designs and human and environmental health. Topics include: imaging; molecular, cell, and tissue engineering; biomechanics; biomedical computation; biochemical engineering; biosensors; and medical devices. Limited enrollment.
1-2 units, Aut (Taylor, C), Win (Taylor, C)

BIOE 391. Directed Study
May be used to prepare for research during a later quarter in 392. Faculty sponsor required. May be repeated for credit.
1-6 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

BIOE 392. Directed Investigation
For Bioengineering graduate students. Previous work in 391 may be required for background; faculty sponsor required. May be repeated for credit.
1-10 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)

BIOE 393. Bioengineering Departmental Research Colloquium
Bioengineering department labs at Stanford present recent research projects and results. Guest lecturers. Topics include applications of engineering to biology, medicine, biotechnology, and medical technology, including biodesign and devices, molecular and cellular engineering, regenerative medicine and tissue engineering, biomedical imaging, and biomedical computation.
1 unit, Aut (Altman, R), Win (Altman, R), Spr (Altman, R)

BIOE 454. Synthetic Biology and Metabolic Engineering
(Same as CHEMENG 454) Principles for the design and optimization of new biological systems. Development of new enzymes, metabolic pathways, other metabolic systems, and communication systems among organisms. Example applications include the production of central metabolites, amino acids, pharmaceutical proteins, and isoprenoids. Economic challenges and quantitative assessment of metabolic performance. Pre- or corequisite: CHEMENG 355 or equivalent.
3 units, Spr (Swartz, J)

BIOE 459. Frontiers in Interdisciplinary Biosciences
(Same as BIO 459, BIOC 459, CHEMENG 459, CHEM 459, PSYCH 459) Students register through their affiliated department; otherwise register for CHEMENG 459. For specialists and non-specialists. Sponsored by the Stanford BioX Program. Three seminars per quarter address scientific and technical themes related to interdisciplinary approaches in bioengineering, medicine, and the chemical, physical, and biological sciences. Leading investigators from Stanford and the world present breakthroughs and endeavors that cut across core disciplines. Pre-seminars introduce basic concepts and background for non-experts. Registered students attend all pre-seminars; others welcome. See http://biox.stanford.edu/courses/459.html. Recommended: basic mathematics, biology, chemistry, and physics.
1 unit, Aut (Robertson, C), Win (Robertson, C), Spr (Robertson, C)

BIOE 484. Computational Methods in Cardiovascular Bioengineering
(Same as ME 484) Lumped parameter, one-dimensional nonlinear and linear wave propagation, and three-dimensional modeling techniques applied to simulate blood flow in the cardiovascular system and evaluate the performance of cardiovascular devices. Construction of anatomic models and extraction of physiologic quantities from medical imaging data. Problems in blood flow within the context of disease research, device design, and surgical planning.
3 units, Spr (Figueroa Alvarez, C)

BIOE 485. Modeling and Simulation of Human Movement
(Same as ME 485) Direct experience with the computational tools used to create simulations of human movement. Lecture/labs on animation of movement; kinematic models of joints; forward dynamic simulation; computational models of muscles, tendons, and ligaments; creation of models from medical images; control of dynamic simulations; collision detection and contact models. Prerequisite: 281, 331A,B, or equivalent.

3 units, not given this year

BIOE 500. Thesis (Ph.D.)

1-15 units, Aut (Staff), Win (Staff), Spr (Staff), Sum (Staff)