BIOENGINEERING

Courses offered by the Department of Bioengineering are listed under the subject code BIOE (https://explorecourses.stanford.edu/search?q=BIOE&view=catalog&page=0&academicYear=&collapse=&filter-coursestatus-Active=on&filter-departmentcode-BIOE=on&filter-catalognumber-BIOE=on) on the *Stanford Bulletin's* ExploreCourses web site.

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 Shriram Center, 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 in the Shriram Center for Bioengineering and Chemical Engineering.

Courses in the teaching program lead to the degrees of Bachelor of Science in Bioengineering, 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.

Mission of the Undergraduate Program in Bioengineering

The Stanford Bioengineering (BioE) major enables students to combine engineering and the life sciences in ways that advance scientific discovery, healthcare and medicine, manufacturing, environmental quality, culture, education, and policy. Students who major in BioE earn a fundamental engineering degree for which the raw materials, underlying basic sciences, fundamental toolkit, and future frontiers are all defined by the unique properties of living systems.

The department offers an undergraduate major in Bioengineering (BioE) leading to the B.S. degree in Bioengineering.

Learning Outcomes (Undergraduate)

The learning outcomes are used in evaluating students as well as the department's undergraduate program. The department expects undergraduate majors in the program to be able to demonstrate the ability to:

1. Apply the knowledge of mathematics, science, and engineering.
2. Design and conduct experiments, as well to analyze and interpret data.
3. Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
4. Function on multidisciplinary teams.
5. Identify, formulate, and solve engineering problems.
6. Understand professional and ethical responsibility.
7. Communicate effectively.
8. Understand the impact of engineering solutions in a global, economic, environmental, and societal context.
9. Demonstrate a working knowledge of contemporary issues.
10. Apply the techniques, skills, and modern engineering tools necessary for engineering practice.
11. Transition from engineering concepts and theory to real engineering applications.

Learning Outcomes (Graduate)

The purpose of the master's program is to provide students with the knowledge and skills necessary for a professional career or doctoral studies. This is done through course work with specialization in an area of the field, including biomedical computation, regenerative medicine and tissue engineering, molecular and cell bioengineering, biomedical imaging, and biomedical devices.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research. Through course work and guided research, the program prepares students to make original contributions in Bioengineering and related fields.

Graduate Programs in Bioengineering

The University's requirements for the M.S. and Ph.D. degrees are outlined in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)" 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, the department requires that students have completed mathematics through multivariable calculus and differential equations, completed a series of undergraduate biology courses 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, 2016.

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

Bachelor of Science in Engineering (Bioengineering)

The department offers an undergraduate major in Bioengineering (BioE) leading to the B.S. degree in Engineering. For additional information, see the *Handbook for Undergraduate Engineering Programs (UGHB)* at http://ughb.stanford.edu.

Bioengineering (BioE)

Completion of the undergraduate program in Bioengineering leads to the conferral of the Bachelor of Science in Bioengineering.

Mission of the Undergraduate Program in Bioengineering

The Stanford Bioengineering (BioE) major enables students to combine engineering and the life sciences in ways that advance scientific discovery, healthcare and medicine, manufacturing, environmental quality, culture, education, and policy. Students who major in BioE earn a fundamental engineering degree for which the raw materials, underlying basic sciences, fundamental toolkit, and future frontiers are all defined by the unique properties of living systems.

Students will complete engineering fundamentals courses, including an introduction to BioE and computer programming. A series of core BioE classes beginning in the second year leads to a student-selected depth area and a senior capstone design project. The department also organizes a summer Research Experience for Undergraduates (REU) (http://bioengineering.stanford.edu/student-resources/reu) program. BioE graduates are well prepared to pursue careers and lead projects in research, medicine, business, law, and policy.

Requirements

Mathematics [1]		
28 units minimum required, see Basic Requirement 1)		
Select one sequence: May also be satisfied with AP Calculus.		
MATH 19 & MATH 20 & MATH 21	Calculus and Calculus and Calculus	10
MATH 41 & MATH 42	Calculus and Calculus	10
Select one of the following:		
CME 100	Vector Calculus for Engineers (Recommended)	5
or MATH 51	Linear Algebra and Differential Calculus of Several Variables	
Select one of the following:		
CME 102	Ordinary Differential Equations for Engineers (Recommended)	5
or MATH 53	Ordinary Differential Equations with Linear Algebra	
Select one of the following:		
CME 104	Linear Algebra and Partial Differential Equations for Engineers (Recommended)	5
or MATH 52	Integral Calculus of Several Variables	
CME 106	Introduction to Probability and Statistics for Engineers (Recommended)	3-5
or STATS 110	Statistical Methods in Engineering and the Physical Sciences	
or STATS 141	Biostatistics	
Science [2]		
28 units minimum:		
CHEM 31X	Chemical Principles Accelerated	5-10
or CHEM 31A & CHEM 31B	Chemical Principles I and Chemical Principles II	
CHEM 33	Structure and Reactivity	5
BIO 41	Genetics, Biochemistry, and Molecular Biology	5
BIO 42	Cell Biology and Animal Physiology	5
PHYSICS 41	Mechanics	4
PHYSICS 43	Electricity and Magnetism	4
Technology in Society		
One course required; course chosen must be on the SoE Approved Courses list at <ughb.stanford.edu> the year taken.		
BIOE 131	Ethics in Bioengineering (WIM)	3
Engineering Fundamentals		
ENGR 70A	Programming Methodology (same as CS 106A)	5
ENGR 80	Introduction to Bioengineering (Engineering Living Matter)	4
Fundamentals Elective; see UGHB Fig. 3-4 for approved course list; may not use ENGR 70B or ENGR 70X		3-5
Bioengineering Core		
BIOE 41	Physical Biology of Macromolecules	4
BIOE 42	Physical Biology of Cells	4
BIOE 44	Fundamentals for Engineering Biology Lab	4
BIOE 51	Anatomy for Bioengineers	4
BIOE 101	Systems Biology	3
BIOE 103	Systems Physiology and Design	4
BIOE 123	Biomedical System Prototyping Lab	4
BIOE 141A	Senior Capstone Design I	4
BIOE 141B	Senior Capstone Design II	4
Bioengineering Depth Electives		
Four courses, minimum 12 units:		12
BIOE 115	Computational Modeling of Microbial Communities	
BIOE 122	Biosecurity and Bioterrorism Response	
BIOE 201C	Diagnostic Devices Lab	
BIOE 211	Biophysics of Multi-cellular Systems and Amorphous Computing	
BIOE 212	Introduction to Biomedical Informatics Research Methodology	
BIOE 214	Representations and Algorithms for Computational Molecular Biology	
BIOE 217	Translational Bioinformatics	
BIOE 220	Introduction to Imaging and Image-based Human Anatomy	
BIOE 221	Physics and Engineering of Radionuclide-based Medical Imaging	
BIOE 222	Instrumentation and Applications for Multi-modality Molecular Imaging of Living Subjects	
BIOE 223	Physics and Engineering of X-Ray Computed Tomography	
BIOE 224	Probes and Applications for Multi-modality Molecular Imaging of Living Subjects	
BIOE 225	Ultrasound Imaging and Therapeutic Applications	
BIOE 227	Functional MRI Methods	
BIOE 244	Advanced Frameworks and Approaches for Engineering Integrated Genetic Systems	
BIOE 231	Protein Engineering	
BIOE 253	Science and Technology Policy	
BIOE 260	Tissue Engineering	
BIOE 279	Computational Biology: Structure and Organization of Biomolecules and Cells	
BIOE 281	Biomechanics of Movement	
BIOE 287	Introduction to Physiology and Biomechanics of Hearing	
BIOE 291	Principles and Practice of Optogenetics for Optical Control of Biological Tissues	
Total Units		118-127

1 It is strongly recommended that CME 100 Vector Calculus for Engineers, CME 102 Ordinary Differential Equations for Engineers, and CME 104 Linear Algebra and Partial Differential Equations for Engineers) be taken rather than MATH 51 Linear Algebra and Differential Calculus of Several Variables, MATH 52 Integral Calculus of Several Variables, and MATH 53 Ordinary Differential Equations with Linear Algebra. CME 106 Introduction to Probability and Statistics for Engineers utilizes MATLAB, a powerful technical computing program, and should be taken rather than STATS 110 Statistical Methods in Engineering and the Physical Sciences or STATS 141 Biostatistics. If you are taking the MATH 50 series, it is strongly recommended to take MATH 51M Introduction to MATLAB or CME 192 Introduction to MATLAB.

[2] Science must include both Chemistry (CHEM 31A Chemical Principles I and CHEM 31B Chemical Principles II; or CHEM 31X Chemical Principles Accelerated) and calculus-based Physics, with two quarters of course work in each, in addition to two courses of BIO core. CHEM 31A Chemical Principles I and CHEM 31B Chemical Principles II are considered one course even though given over two quarters.

For additional information and sample programs see the Handbook for Undergraduate Engineering Programs (UGHB) (http://ughb.stanford.edu). Students pursuing a premed program need to take additional courses; see the UGHB, BioE Premed 4-Year Plan.

Honors Program

The School of Engineering offers a program leading to a Bachelor of Science in Bioengineering with Honors (BIOE-BSH). This program provides the opportunity for qualified BioE majors to conduct independent research at an advanced level with a faculty research adviser and documented in an honors thesis.

In order to receive departmental honors, students admitted to the program must:

1. Declare the honors program in Axess (BIOE-BSH).
2. Maintain an overall grade point average (GPA) of at least 3.5 as calculated on the unofficial transcript.
3. Complete at least two quarters of research with a minimum of nine units of BIOE 191 Bioengineering Problems and Experimental Investigation or BIOE 191X Out-of-Department Advanced Research Laboratory in Bioengineering for a letter grade; up to three units may be used towards the bioengineering depth elective requirements.
4. Submit a completed thesis draft to the honors adviser and second reader by the third week of Spring Quarter. Further revisions and final endorsement are to be finished by the second Monday in May, when two signed bound copies plus one PC-compatible CD-ROM are to be submitted to the student services officer.
5. Attend the Bioengineering Honors Symposium at the end of Spring Quarter and give a poster or oral presentation, or present in another approved suitable forum.

For more information and application instructions, see the Bioengineering Honors Program (http://bioengineering.stanford.edu/academics/undergraduate-programs/bioengineering-honors-program) web site.

Coterminal Master's Program in Bioengineering

This option is available to 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.

The University minimum requirements for the coterminal program are 180 units for the bachelor's degree plus 45 unduplicated units for the master's degree.

In order to apply for the coterminal master's program student's must have completed six, non-summer quarters at Stanford (two non-summer quarters for transfer students), have completed 120 undergraduate units, and must have declared the undergraduate major. 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 November 1, 2016. Students interested in the coterminal master's degree must take the Graduate Record Examination (GRE) (http://www.gre.org). Prospective applicants should see the department's web site for application form, instructions, and supporting documents (http://bioengineering.stanford.edu/admissions/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.

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (http://exploredegrees.stanford.edu/cotermdegrees)" section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate adviser be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

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.

Requirements

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

1. Core Bioengineering courses (10-11 units)

The following courses are required:

		Units
BIOE 300A	Molecular and Cellular Bioengineering	3
BIOE 300B	Engineering Concepts Applied to Physiology	3
Select two of the following:		4-5
BIOE 301A	Molecular and Cellular Engineering Lab	
BIOE 301B	Clinical Needs and Technology	

BIOE 301C	Diagnostic Devices Lab	
Total Units		10-11

These courses, together with the approved technical electives, should form a cohesive course of study that provides depth and breadth.

2. Approved Technical Electives (26 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 (4 units)

The seminar units should be fulfilled through:

		Units
BIOE 393	Bioengineering Departmental Research Colloquium	3
MED 255	The Responsible Conduct of Research	1
Total Units		4

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 must:

1. 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
2. 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 ExploreCourses for course descriptions.

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.

Chair: Norbert J. Pelc

Professors: Russ B. Altman, Kwabena Boahen, Dennis R. Carter, Karl Deisseroth, Scott L. Delp, Norbert J. Pelc, Stephen R. Quake, Matthew Scott, James R. Swartz, Paul Yock

Associate Professors: Annelise E. Barron, Zev David Bryant, Jennifer R. Cochran, Markus Willard Covert, Andrew Endy, Kerwyn C. Huang, Jan T. Liphardt, Christina D. Smolke

Assistant Professors: David B. Camarillo, Polly M. Fordyce, Jin Hyung Lee, Michael Lin, Manu Prakash, Stanley S. Qi, Ingmar Riedel-Kruse, Bo Wang, Fan Yang

Courtesy Professors: Christopher H. Contag, Bruce L. Daniel, Daniel S. Fisher, Sanjiv S. Gambhir, Garry E. Gold, Stuart B. Goodman, Geoffrey C. Gurtner, Brian Hargreaves, Thomas M. Krummel, Craig Levin, Michael T. Longaker, David Magnus, Lloyd B. Minor, Krishna Shenoy, Paul J. Wang, Joseph Woo

Courtesy Associate Professors: Beth Pruitt, Jeffrey A. Feinstein, Garry E. Gold, Brian Hargreaves, Kim Butts Pauly, Marc E. Levenston, Sakti Srivastava, Yunzhi Peter Yang

Courtesy Assistant Professors: Sarah Heilshorn, Ellen Kuhl, James K. Wall

Consulting Faculty: Todd Brinton, Stephen Fodor, Uday Kumar, John LinehanJ, Marc L. Salit, Gordon Saul, Charles A. Taylor

Lecturer: Natalia Khuri, Joesph Mandato, Ryan K. Piece, Kara H. Rogers, Ross D. Venook

Graduate Related Courses

		Units
BIOMEDIN 210	Modeling Biomedical Systems: Ontology, Terminology, Problem Solving	3
BIOMEDIN 217	Translational Bioinformatics	4

EE 369A	Medical Imaging Systems I	3
EE 369B	Medical Imaging Systems II	3
ME 287	Mechanics of Biological Tissues	3

Courses

BIOE 10N. Form and Function of Animal Skeletons. 3 Units.
Preference to freshmen. The biomechanics and mechanobiology of the musculoskeletal system in human beings and other vertebrates on the level of the whole organism, organ systems, tissues, and cell biology. Field trips to labs.
Same as: ME 10N

BIOE 32Q. Bon Appétit, Marie Curie! The Science Behind Haute Cuisine. 3 Units.
This seminar is for anyone who loves food, cooking or science! We will focus on the science and biology behind the techniques and the taste buds. Not a single lecture will pass by without a delicious opportunity - each weekly meeting will include not only lecture, but also a lab demonstration and a chance to prepare classic dishes that illustrate that day's scientific concepts.

BIOE 36Q. The Biophysics of Innate Immunity. 3 Units.
The innate immune system provides our first line of defense against disease--bothninfections, and cancer. Innate immune effectors such as host defense peptides arendeployed by numerous cell types (for instance neutrophils, macrophages, NK cells,nepithelial cells and keratinocytes) and work by biophysical mechanisms of action. The ourse draws from the primary literature and covers the evolution, structures, mechanisms,and physiological functions of important "innate immune effectors" (components of the innate immune system that can attack pathogens, and infected or host cells, and kill or incapacitate them directly). The course is aimed at students who have an interest in biochemistry, molecular/cellular biology, biophysics, and/or bioengineering.

BIOE 41. Physical Biology of Macromolecules. 4 Units.
Principles of statistical physics, thermodynamics, and kinetics with applications to molecular biology. Topics include entropy, temperature, chemical forces, enzyme kinetics, free energy and its uses, self assembly, cooperative transitions in macromolecules, molecular machines, feedback, and accurate replication. Prerequisites: MATH 41, 42; CHEM 31A, B (or 31X); strongly recommended: PHYSICS 41, CME 100 or MATH 51, and CME 106; or instructor approval.

BIOE 42. Physical Biology of Cells. 4 Units.
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. Prerequisites: MATH 41, 42; CHEM 31A, B (or 31X); strongly recommended: CS 106A, PHYSICS 41, CME 100 or MATH 51, and CME 106; or instructor approval. 4 units, Spr (Huang, K).

BIOE 44. Fundamentals for Engineering Biology Lab. 4 Units.
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. Concurrent or previous enrollment in BIO 41.

BIOE 51. Anatomy for Bioengineers. 4 Units.
Fundamental human anatomy, spanning major body systems and tissues including nerve, muscle, bone, cardiovascular, respiratory, gastrointestinal, and renal systems. Explore intricacies of structure and function, and how various body parts come together to form a coherent and adaptable living being. Correlate clinical conditions and therapeutic interventions. Participate in lab sessions with predissected cadaveric material and hands-on learning to gain understanding of the bioengineering human application domain. Encourage anatomical thinking, defining challenges and opportunities for bioengineers.

BIOE 70Q. Medical Device Innovation. 3 Units.
BIOE 70Q invites students to apply design thinking to the creation of healthcare technologies. Students will learn about the variety of factors that shape healthcare innovation, and through hands-on design projects, invent their own solutions to clinical needs. Guest instructors will include engineers, doctors, entrepreneurs, and others who have helped bring ideas from concept to clinical use.

BIOE 80. Introduction to Bioengineering (Engineering Living Matter). 4 Units.
Students completing BIOE.80 should have a working understanding for how to approach the systematic engineering of living systems to benefit all people and the planet. Our main goals are (1) to help students learn ways of thinking about engineering living matter and (2) to empower students to explore the broader ramifications of engineering life. Specific concepts and skills covered include but are not limited to: capacities of natural life on Earth; scope of the existing human-directed bioeconomy; deconstructing complicated problems; reaction & diffusion systems; microbial human anatomy; conceptualizing the engineering of biology; how atoms can be organized to make molecules; how to print DNA from scratch; programming genetic sensors, logic, & actuators; biology beyond molecules (photons, electrons, etc.); what constraints limit what life can do?; what will be the major health challenges in 2030?; how does what we want shape bioengineering?; who should choose and realize various competing bioengineering futures?.
Same as: ENGR 80

BIOE 101. Systems Biology. 3 Units.
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: CME 102; BIO 41, BIO 42; or consent of instructor.
Same as: BIOE 210

BIOE 103. Systems Physiology and Design. 4 Units.
Physiology of intact human tissues, organs, and organ systems in health and disease, and bioengineering tools used (or needed) to probe and model these physiological systems. Topics: Clinical physiology, network physiology and system design/plasticity, diseases and interventions (major syndromes, simulation, and treatment, instrumentation for intervention, stimulation, diagnosis, and prevention), and new technologies including tissue engineering and optogenetics. Discussions of pathology of these systems in a clinical-case based format, with a view towards identifying unmet clinical needs. Learning computational skills that not only enable simulation of these systems but also apply more broadly to biomedical data analysis. Prerequisites: CME 102; PHYSICS 41; BIO 41, 42.

BIOE 103B. Systems Physiology and Design. 4 Units.
ONLINE Offering of BIOE103. This pilot class, BIOE103B, is an entirely online offering with the same content, learning goals, and prerequisites as BIOE103. Students attend class by watching videos and completing assignments remotely. Students may attend recitation and office hours in person, but cannot attend the BIOE103 in-person lecture due to room capacity restraints. Physiology of intact human tissues, organs, and organ systems in health and disease, and bioengineering tools used (or needed) to probe and model these physiological systems. Topics: Clinical physiology, network physiology and system design/plasticity, diseases and interventions (major syndromes, simulation, and treatment, instrumentation for intervention, stimulation, diagnosis, and prevention), and new technologies including tissue engineering and optogenetics. Discussions of pathology of these systems in a clinical-case based format, with a view towards identifying unmet clinical needs. Learning computational skills that not only enable simulation of these systems but also apply more broadly to biomedical data analysis. Prerequisites: MATH 41, 42; CME 102; PHY 41; BIO 41, 42; strongly recommended PHY 43; or instructor approval.

BIOE 115. Computational Modeling of Microbial Communities. 4 Units.
Provides biologists with basic computational tools and knowledge to confront large datasets in a quantitative manner. Students learn basic programming skills focused on Matlab, but also are introduced to Perl and Python. Topics include: image analysis, bioinformatics algorithms, reaction diffusion modeling, Monte Carlo algorithms, and population dynamics. Students apply computational skills to a miniature research project studying the human gut microbiota.
Same as: MI 245

BIOE 122. Biosecurity and Bioterrorism Response. 4-5 Units.
Overview of the most pressing biosecurity issues facing the world today. Guest lecturers have included former Secretary of State Condoleezza Rice, former Special Assistant on BioSecurity to Presidents Clinton and Bush Jr. Dr. Ken Bernard, Chief Medical Officer of the Homeland Security Department Dr. Alex Garza, eminent scientists, innovators and physicians in the field, and leaders of relevant technology companies. How well the US and global healthcare systems are prepared to withstand a pandemic or a bioterrorism attack, how the medical/healthcare field, government, and the technology sectors are involved in biosecurity and pandemic or bioterrorism response and how they interface, the rise of synthetic biology with its promises and threats, global bio-surveillance, making the medical diagnosis, isolation, containment, hospital surge capacity, stockpiling and distribution of countermeasures, food and agriculture biosecurity, new promising technologies for detection of bio-threats and countermeasures. Open to medical, graduate, and undergraduate students. No prior background in biology necessary. 4 units for twice weekly attendance (Mon. and Wed.); additional 1 unit for writing a research paper for 5 units total maximum.
Same as: EMED 122, PUBLPOL 122

BIOE 123. Biomedical System Prototyping Lab. 4 Units.
The Bioengineering System Prototyping Laboratory is a fast-paced, team-based system engineering experience, in which teams of 2-3 students design and build a fermenter that meets a set of common requirements along with a set of unique team-determined requirements. Students learn-by-doing hands-on skills in electronics and mechanical design and fabrication. Teams also develop process skills and an engineering mindset by aligning specifications with requirements, developing output metrics and measuring performance, and creating project proposals and plans. The course culminates in demonstration of a fully functioning fermenter that meets the teams' self-determined metrics.nnLearning goals:n1. Hands-on skills and experience with design, fabrication, integration, and characterization of practical electronic and mechanical hardware systems relevant to Bioengineeringn2. Practice using modern rapid prototyping and device equipment and techniques, including CAD, 3D printing, laser cutting, microcontrollers, design thinkingn3. Experience working as a team to build an end-to-end functional biomedical system (e.g., a fermenter)nnPrerequisites: BIOE 41 and Matlab recommended.

BIOE 131. Ethics in Bioengineering. 3 Units.
Bioengineering focuses on the development and application of new technologies in the biology and medicine. These technologies often have powerful effects on living systems at the microscopic and macroscopic level. They can provide great benefit to society, but they also can be used in dangerous or damaging ways. These effects may be positive or negative, and so it is critical that bioengineers understand the basic principles of ethics when thinking about how the technologies they develop can and should be applied. On a personal level, every bioengineer should understand the basic principles of ethical behavior in the professional setting. This course will involve substantial writing, and will use case-study methodology to introduce both societal and personal ethical principles, with a focus on practical applications.
Same as: ETHICSOC 131X

BIOE 141A. Senior Capstone Design I. 4 Units.
Lecture/Lab. First course of two-quarter capstone sequence. Team based project introduces students to the process of designing new biological technologies to address societal needs. Topics include methods for validating societal needs, brainstorming, concept selection, and the engineering design process. First quarter deliverable is a design for the top concept. Second quarter involves implementation and testing. Guest lectures and practical demonstrations are incorporated. Prerequisites: BIOE 123 and BIOE 44. This course is open only to seniors in the undergraduate Bioengineering program.

BIOE 141B. Senior Capstone Design II. 4 Units.
Lecture/Lab. Second course of two-quarter capstone sequence. Team based project introduces students to the process of designing new biological technologies to address societal needs. Emphasis is on implementing and testing the design from the first quarter with the at least one round of prototype iteration. Guest lectures and practical demonstrations are incorporated. Prerequisites: BIOE123 and BIOE44. This course is open only to seniors in the undergraduate Bioengineering program.nIMPORTANT NOTE: class meets in Shriram 112.

BIOE 158. Soft Matter in Biomedical Devices, Microelectronics, and Everyday Life. 4 Units.
The relationships between molecular structure, morphology, and the unique physical, chemical, and mechanical behavior of polymers and other types of ¿soft matter¿ are discussed. Topics include methods for preparing synthetic polymers and examination of how enthalpy and entropy determine conformation, solubility, mechanical behavior, microphase separation, crystallinity, glass transitions, elasticity, and linear viscoelasticity. Case studies covering polymers in biomedical devices and microelectronics will be covered. Prerequisites: ENG 50 or equivalent.
Same as: CHEMENG 160, MATSCI 158

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

BIOE 191X. Out-of-Department Advanced Research Laboratory in Bioengineering. 1-15 Unit.
Individual research by arrangement with out-of-department instructors. Credit for 191X is restricted to declared Bioengineering majors pursuing honors and requires department approval. See http://bioengineering.stanford.edu/education/undergraduate.html for additional information. May be repeated for credit.

BIOE 196. INTERACTIVE MEDIA AND GAMES. 1 Unit.
Interactive media and games increasingly pervade and shape our society. In addition to their dominant roles in entertainment, video games play growing roles in education, arts, and science. This seminar series brings together a diverse set of experts to provide interdisciplinary perspectives on these media regarding their history, technologies, scholarly research, industry, artistic value, and potential future.
Same as: BIOPHYS 196

BIOE 201C. Diagnostic Devices Lab. 2 Units.
This course exposes students to the engineering principles and clinical application of medical devices through lectures and hands-on labs, performed in teams of two. Teams take measurements with these devices and fit their data to theory presented in the lecture. Devices covered include X-ray, CT, MRI, EEG, ECG, Ultrasound and BMI (Brain-machine interface). Prerequisites: BioE 103 or BioE 300B or EE 122B.
Same as: BIOE 301C

BIOE 210. Systems Biology. 3 Units.
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: CME 102; BIO 41, BIO 42; or consent of instructor.
Same as: BIOE 101

BIOE 211. Biophysics of Multi-cellular Systems and Amorphous Computing. 2-3 Units.
Provides an interdisciplinary perspective on the design, emergent behavior, and functionality of multi-cellular biological systems such as embryos, biofilms, and artificial tissues and their conceptual relationship to amorphous computers. Students discuss relevant literature and introduced to and apply pertinent mathematical and biophysical modeling approaches to various aspect multi-cellular systems, furthermore carry out real biology experiments over the web. Specific topics include: (Morphogen) gradients; reaction-diffusion systems (Turing patterns); visco-elastic aspects and forces in tissues; morphogenesis; coordinated gene expression, genetic oscillators and synchrony; genetic networks; self-organization, noise, robustness, and evolvability; game theory; emergent behavior; criticality; symmetries; scaling; fractals; agent based modeling. The course is geared towards a broadly interested graduate and advanced undergraduates audience such as from bio / applied physics, computer science, developmental and systems biology, and bio / tissue / mechanical / electrical engineering. Prerequisites: Previous knowledge in one programming language - ideally Matlab - is recommended; undergraduate students benefit from BIOE 41, BIOE 42, or equivalent.
Same as: BIOE 311, BIOPHYS 311, DBIO 211

BIOE 212. Introduction to Biomedical Informatics Research Methodology. 3-5 Units.
Capstone Biomedical Informatics (BMI) experience. 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. Issues related to research reproducibility. Guest lectures from professional biomedical informatics systems builders on issues related to the process of project management. Software engineering basics. Because the team projects start in the first week of class, attendance that week is strongly recommended. Prerequisites: BIOMEDIN 210 or 211 or 214 or 217. Preference to BMI graduate students. Consent of instructor required.
Same as: BIOMEDIN 212, CS 272, GENE 212

BIOE 213. Stochastic and Nonlinear Dynamics. 3 Units.
Theoretical analysis of dynamical processes: dynamical systems, stochastic processes, and spatiotemporal dynamics. Motivations and applications from biology and physics. Emphasis is on methods including qualitative approaches, asymptotics, and multiple scale analysis. Prerequisites: ordinary and partial differential equations, complex analysis, and probability or statistical physics.
Same as: APPPHYS 223, BIO 223

BIOE 214. Representations and Algorithms for Computational Molecular Biology. 3-4 Units.
Topics: introduction to bioinformatics and computational biology, algorithms for alignment of biological sequences and structures, computing with strings, phylogenetic tree construction, hidden Markov models, 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. Prerequisite: CS 106B; recommended: CS161; consent of instructor for 3 units.
Same as: BIOMEDIN 214, CS 274, GENE 214

BIOE 215. Physics-Based Simulation of Biological Structure. 3 Units.
Modeling, simulation, analysis, and measurement of biological systems. Computational tools for determining the behavior of biological structures-from molecules to organisms. Numerical solutions of algebraic and differential equations governing biological processes. Simulation laboratory examples in biology, engineering, and computer science. Limited enrollment. Prerequisites: basic biology, mechanics (F=ma), ODEs, and proficiency in C or C++ programming.

BIOE 217. Translational Bioinformatics. 4 Units.
Computational methods for the translation of biomedical data into diagnostic, prognostic, and therapeutic applications in medicine. Topics: multi-scale omics data generation and analysis, utility and limitations of public biomedical resources, machine learning and data mining, issues and opportunities in drug discovery, and mobile/digital health solutions. Case studies and course project. Prerequisites: programming ability at the level of CS 106A and familiarity with biology and statistics.
Same as: BIOMEDIN 217, CS 275

BIOE 219. Special Topics in Development and Cancer: Evolutionary and Quantitative Perspectives. 3 Units.
The course will serve as a literature-based introductory guide for synthesis of ideas in developmental biology and cancer, with an emphasis on evolutionary analysis and quantitative thinking. The goal for this course is for students to understand how we know what we know about fundamental questions in the field of developmental biology and cancer, and how we ask good questions for the future. We will discuss how studying model organisms has provided the critical breakthroughs that have helped us understand developmental and disease mechanisms in higher organisms. The students are expected to be able to read the primary literature and think critically about experiments to understand what is actually known and what questions still remain unanswered. Students will develop skills in the educated guesswork to apply order-of-magnitude methodology to questions in development and cancer.
Same as: DBIO 219

BIOE 220. Introduction to Imaging and Image-based Human Anatomy. 3 Units.
Focus on learning the fundamentals of each imaging modality including X-ray Imaging, Ultrasound, CT, and MRI, to learn normal human anatomy and how it appears on medical images, to learn the relative strengths of the modalities, and to answer, "What am I looking at?" Course website: http://bioe220.stanford.edu.
Same as: RAD 220

BIOE 221. Physics and Engineering of Radionuclide-based Medical Imaging. 3 Units.
Physics, instrumentation, and algorithms for radionuclide-based medical imaging, with a focus on positron emission tomography (PET) and single photon emission computed tomography (SPECT). Topics include basic physics of photon emission from the body and detection, sensors, readout and data acquisition electronics, system design, strategies for tomographic image reconstruction, system calibration and data correction algorithms, methods of image quantification, and image quality assessment, and current developments in the field. Prerequisites: A year of university-level mathematics and physics.
Same as: RAD 221

BIOE 221G. Gut Microbiota in Health and Disease. 2-3 Units.
Preference to graduate students. Focus is on the human gut microbiota. Students enrolling for 3 units receive instruction on computational approaches to analyze microbiome data and must complete a related project.
Same as: GENE 208, MI 221

BIOE 222. Instrumentation and Applications for Multi-modality Molecular Imaging of Living Subjects. 3-4 Units.
Focuses on instruments, algorithms and other technologies for imaging of cellular and molecular processes in living subjects. Introduces preclinical and clinical molecular imaging modalities, including strategies for molecular imaging using PET, SPECT, MRI, Ultrasound, Optics, and Photoacoustics. Covers basics of instrumentation physics, the origin and properties of the signal generation, and image data quantification.nnhttp://med.stanford.edu/mips/education/bioe222/2016.html.
Same as: RAD 222

BIOE 223. Physics and Engineering of X-Ray Computed Tomography. 3 Units.
CT scanning geometries, production of x-rays, interactions of x-rays with matter, 2D and 3D CT reconstruction, image presentation, image quality performance parameters, system components, image artirfacts, radiation dose. Prerequisites: differential and integral calculus. Knowledge of Fourier transforms (EE261) recommended.
Same as: RAD 223

BIOE 224. Probes and Applications for Multi-modality Molecular Imaging of Living Subjects. 4 Units.
Focuses on molecular contrast agents (a.k.a. "probes") that interrogate and target specific cellular and molecular disease mechanisms. Covers the ideal characteristics of molecular probes and how to optimize their design for use as effective imaging reagents that enables readout of specific steps in biological pathways and reveal the nature of disease through noninvasive imaging assays. Prerequisites: none.
Same as: RAD 224

BIOE 225. Ultrasound Imaging and Therapeutic Applications. 3 Units.
Covers the basic concepts of ultrasound imaging including acoustic properties of biological tissues, transducer hardware, beam formation, and clinical imaging. Also includes the therapeutic applications of ultrasound including thermal and mechanical effects, visualization of the temperature and radiation force with MRI, tissue assessment with MRI and ultrasound, and ultrasound-enhanced drug delivery. Course website: http://bioe225.stanford.edu.
Same as: RAD 225

BIOE 227. Functional MRI Methods. 3 Units.
(Same as RAD 227, BIOPHYS 227) Basics of functional magnetic resonance neuroimaging, including data acquisition, analysis, and experimental design. Journal club sections. Cognitive neuroscience and clinical applications. Prerequisites: basic physics, mathematics; neuroscience recommended.

BIOE 229. Advanced Research Topics in Multi-modality Molecular Imaging of Living Subjects. 3-4 Units.
Covers advanced topics and controversies in molecular imaging in the understanding of biology and disease. Lectures will include discussion on instrumentation, probes and bioassays. Topics will address unmet needs for visualization and quantification of molecular pathways in biology as well as for diagnosis and disease management. Areas of unmet clinical needs include those in oncology, neurology, cardiovascular medicine and musculoskeletal diseases. The aim is to identify important problems and controversies in a field and address them by providing background and relevance through review of the relevant primary literature, and then proposing and evaluating innovative imaging strategies that are designed to address the problem. The organization of lectures is similar to the thought process that is necessary for writing an NIH grant proposal in which aims are proposed and supported by background and relevance. The innovation of proposed approaches will be highlighted. An aim of the course is to inform students on how to creatively think about a problem and propose a solution focusing on the key elements of writing a successful grant proposal. Prerequisites: none.

BIOE 231. Protein Engineering. 3 Units.
The design and engineering of biomolecules emphasizing proteins, antibodies, and enzymes. Combinatorial and rational methodologies, protein structure and function, and biophysical analyses of modified biomolecules. Clinically relevant examples from the literature and biotech industry. Prerequisite: basic biochemistry. Winter, Cochran.
Same as: BIOE 331

BIOE 236. Biophysical Mechanisms of Innate Immunity. 3 Units.
The innate immune system provides our first line of defense against infections of all kinds as well as cancer. Innate immune effectors, e.g. host defense peptides are deployed by numerous cell types (neutrophils, macrophages, NK cells, as well as epithelial cells, keratinocytes, and others) and attack by biophysical mechanisms of action. Disorders of innate immunity are increasingly being implicated in human autoimmune disease. Using primary literature, we will cover the evolution, structures, mechanisms, and functions of innate immune effectors.

BIOE 238. Principles and Tools for Metrology in Biology. 2 Units.
A practical introduction to the science of measurement. Emphasis is on the tools used to parse a biological measurement problem. Students will learn to identify and quantitatively address the critical sources of variability and bias using the core concepts of uncertainty, traceability, and validation. Case studies will illustrate use of metrology in current and emergent bioscience and engineering applications.

BIOE 241. Biological Macromolecules. 3-5 Units.
The physical and chemical basis of macromolecular function. Topics include: forces that stabilize macromolecular structure and their complexes; thermodynamics and statistical mechanics of macromolecular folding, binding, and allostery; diffusional processes; kinetics of enzymatic processes; the relationship of these principles to practical application in experimental design and interpretation. The class emphasizes interactive learning, and is divided equally among lectures, in-class group problem solving, and discussion of current and classical literature. Enrollment limited to 50. Prerequisites: Background in biochemistry and physical chemistry recommended but material available for those with deficiency in these areas; undergraduates with consent of instructor only.
Same as: BIOC 241, BIOPHYS 241, SBIO 241

BIOE 242. LAW, TECHNOLOGY, AND LIBERTY. 2 Units.
New technologies from gene editing to networked computing have already transformed our economic and social structures and are increasingly changing what it means to be human. What role has law played in regulating and shaping these technologies? And what role can and should it play in the future? This seminar will consider these and related questions, focusing on new forms of networked production, the new landscape of security and scarcity, and the meaning of human nature and ecology in an era of rapid technological change. Readings will be drawn from a range of disciplines, including science and engineering, political economy, and law. The course will feature several guest speakers. There are no formal prerequisites in either engineering or law, but students should be committed to pursuing novel questions in an interdisciplinary context. The enrollment goal is to balance the class composition between law and non-law students. Elements used in grading: Attendance, Class Participation, Written Assignments. CONSENT APPLICATION: To apply for this course, students must complete and submit a Consent Application Form available on the SLS website (Click Courses at the bottom of the homepage and then click Consent of Instructor Forms). See Consent Application Form for instructions and submission deadline. This course is cross-listed with the School of Engineering (TBA). May be repeat for credit.
Same as: ENGR 243

BIOE 244. Advanced Frameworks and Approaches for Engineering Integrated Genetic Systems. 4 Units.
Concepts and techniques for the design and implementation of engineered genetic systems. Topics covered include the quantitative exploration of tools that support (a) molecular component engineering, (b) abstraction and composition of functional genetic devices, (c) use of control and dynamical systems theory in device and systems design, (d) treatment of molecular "noise", (e) integration of DNA-encoded programs within cellular chassis, (f) designing for evolution, and (g) the use of standards in measurement, genetic layout architecture, and data exchange. Prerequisites: CME104, CME106, CHEM 33, BIO41, BIO42, BIOE41, BIOE42, and BIOE44 (or equivalents), or permission of the instructors.

BIOE 248. Neuroengineering Laboratory. 3 Units.
Laboratory course exploring the basics of neuroelectrophysiology, neuroengineering, and closed-loop neural decoding. Course will use low-cost electrophysiological amplifying equipment and a real-time recording and computational system to measure neural action potentials from invertebrates, record electromyography from people, and create real-time neural decoders for closed-loop human movement control experiments. Fundamental properties of neurons and systems neuroscience will be experimentally verified. Engineering concepts surrounding neural decoders will be explored. Final project in the course will be a student-conceived in-depth experiment. More information and enrollment instructions are at http://bil.stanford.edu/class.
Same as: NSUR 248

BIOE 253. Science and Technology Policy. 3-4 Units.
How U.S. and international political institutions and processes govern science and technology; the roles of scientists, engineers, and physicians in creating and implementing policies; introduction to analytical techniques that are common to research and policy analysis in technology and public policy; and examples from specific mission areas (e.g., economic growth, health, climate, energy and the environment, information technology, international security). Assignments: analyzing the politics of particular legislative outcomes, assessing options for trying to reach a policy objective, and preparing a mock policy memo and congressional testimony.
Same as: PUBLPOL 353

BIOE 256. Technology Assessment and Regulation of Medical Devices. 3 Units.
Regulatory approval and reimbursement for new health technologies are critical success factors for product commercialization. This course explores the regulatory and payer environment in the U.S. and abroad, as well as common methods of health technology assessment. Students will learn frameworks to identify factors relevant to the adoption of new health technologies, and the management of those factors in the design and development phases of bringing a product to market through case studies, guest speakers from government (FDA) and industry, and a course project.
Same as: MS&E 256

BIOE 260. Tissue Engineering. 4 Units.
Principles of tissue engineering and design strategies for practical applications for tissue repair. Topics include tissue morphogenesis, stem cells, biomaterials, controlled drug and gene delivery, and paper discussions. Students will learn skills for lab research through interactive lectures, paper discussions and research proposal development. Students work in small teams to work on develop research proposal for authentic tissue engineering problems. Lab sessions will teach techniques for culturing cells in 3D, as well as fabricating and characterizing hydrogels as 3D cell niche.
Same as: ORTHO 260

BIOE 261. Principles and Practice of Stem Cell Engineering. 3 Units.
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.
Same as: NSUR 261

BIOE 273. Biodesign for Mobile Health. 1-3 Unit.
This course examines the emerging mobile health industry. Mobile health refers to the provision of health services and information via digital technologies such as mobile phones and wearable sensors. Faculty from Stanford University and other academic institutions, as well as guest lecturers from the mobile health industry discuss factors driving needs in the field, explore opportunities and challenges that characterize the emerging mobile health innovation landscape, and present an overview of the technologies, initiatives, and companies that are transforming the way we access health care today.
Same as: MED 273

BIOE 279. Computational Biology: Structure and Organization of Biomolecules and Cells. 3 Units.
Computational techniques for investigating and designing the three-dimensional structure and dynamics of biomolecules and cells. These computational methods play an increasingly important role in drug discovery, medicine, bioengineering, and molecular biology. Course topics include protein structure prediction, protein design, drug screening, molecular simulation, cellular-level simulation, image analysis for microscopy, and methods for solving structures from crystallography and electron microscopy data. Prerequisites: elementary programming background (CS 106A or equivalent) and an introductory course in biology or biochemistry.
Same as: BIOMEDIN 279, BIOPHYS 279, CME 279, CS 279

BIOE 280. Skeletal Development and Evolution. 3 Units.
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: BIO 42, and ME 80 or BIOE 42.
Same as: ME 280

BIOE 281. Biomechanics of Movement. 3 Units.
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.
Same as: ME 281

BIOE 282. Performance, Development, and Adaptation of Skeletal Muscle. 3 Units.
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. Applications due Friday, September 16th by 5pm. Applications available at http://bioe282.stanford.edu/. Prerequisites: engineering or biology core coursework. Fall (Cromie, Liske, Steele, Delp).

BIOE 283. Mechanotransduction in Cells and Tissues. 3 Units.
Mechanical cues play a critical role in development, normal functioning of cells and tissues, and various diseases. This course will cover what is known about cellular mechanotransduction, or the processes by which living cells sense and respond to physical cues such as physiological forces or mechanical properties of the tissue microenvironment. Experimental techniques and current areas of active investigation will be highlighted.
Same as: BIOPHYS 244, ME 244

BIOE 284B. Cardiovascular Bioengineering. 3 Units.
Continuation of ME/BIOE 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.
Same as: ME 284B

BIOE 285. Computational Modeling in the Cardiovascular System. 3 Units.
This course introduces computational modeling methods for cardiovascular blood flow and physiology. Topics in this course include analytical and computational methods for solutions of flow in deformable vessels, one-dimensional equations of blood flow, cardiovascular anatomy, lumped parameter models, vascular trees, scaling laws, biomechanics of the circulatory system, and 3D patient specific modeling with finite elements; course will provide an overview of the diagnosis and treatment of adult and congenital cardiovascular diseases and review recent research in the literature in a journal club format. Students will use SimVascular software to do clinically-oriented projects in patient specific blood flow simulations.
Same as: CME 285, ME 285

BIOE 287. Introduction to Physiology and Biomechanics of Hearing. 3 Units.
Hearing is fundamental to our ability to communicate, yet in the US alone over 30 million people suffer some form of hearing impairment. As engineers and scientists, it is important for us to understand the underlying principles of the auditory system if we are to devise better ways of helping those with hearing loss. The goal of this course is to introduce undergraduate and graduate students to the anatomy, physiology, and biomechanics of hearing. Principles from acoustics, mechanics, and hydrodynamics will be used to build a foundational understanding of one of the most complex, interdisciplinary, and fascinating areas of biology. Topics include the evolution of hearing, computational modeling approaches, fluid-structure interactions, ion-channel transduction, psychoacoustics, diagnostic tools, and micrometer to millimeter scale imaging methods. We will also study current technologies for mitigating hearing loss via passive and active prostheses, as well as future regenerative therapies.
Same as: ME 166, ME 266

BIOE 291. Principles and Practice of Optogenetics for Optical Control of Biological Tissues. 3 Units.
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.

BIOE 299B. Practical Training. 1 Unit.
For Ph.D. students. Educational opportunities in high technology research and development labs in industry. Students engage in internship work and integrate that work into their academic program. Following internship work, students complete a research report outlining work activity, problems investigated, key results, and follow-up projects they expect to perform. Meets the requirements for curricular practical training for students on F-1 visas. Student is responsible for arranging own internship/employment and faculty sponsorship. Register under faculty sponsor's section number. All paperwork must be completed by student and faculty sponsor, as the student services office does not sponsor CPT. Students are allowed only two quarters of CPT per degree program. Course may be repeated twice.

BIOE 300A. Molecular and Cellular Bioengineering. 3 Units.
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.

BIOE 300B. Engineering Concepts Applied to Physiology. 3 Units.
This course focuses on engineering approaches to quantifying, modeling and controlling the physiology and pathophysiology of complex systems, from the level of individual cells to tissue, organ and multi-organ systems.

BIOE 300C. Medical Devices, Diagnostics, and Pharmaceuticals: Technologies, Regulation, and Applications. 3 Units.
Preference to Bioengineering graduate students. Major classes of technologies including imaging techniques, chemical diagnostics, drug design and delivery. Topics include pacemakers, fMRI, PCR, stents, and biomaterials. Principles, practical limitations, and feature trade-offs in clinical settings.

BIOE 301A. Molecular and Cellular Engineering Lab. 2 Units.
Preference to Bioengineering graduate students. Practical applications of biotechnology and molecular bioengineering including recombinant DNA techniques, molecular cloning, microbial cell growth and manipulation, and library screening. Emphasis is on experimental design and data analysis. Limited enrollment. Fall.

BIOE 301B. Clinical Needs and Technology. 2 Units.
The goal of this course is to introduce bioengineering students to medical technology as it is used in current clinical practice, in the modern tertiary care, subspecialty hospital. Half of the course will be devoted to labs, in which small groups of students participate in hands-on experiences using advanced clinical technology in areas such as medical imaging, robotic surgery, and minimally invasive diagnosis and treatment. The second half of the course brings pairs of students and clinical faculty mentors together for a more in-depth, focused exposure to clinical care in one specific area. Final grades will be based on attendance, and presentations made by each pair of student to the class about their mentoring experience.

BIOE 301C. Diagnostic Devices Lab. 2 Units.
This course exposes students to the engineering principles and clinical application of medical devices through lectures and hands-on labs, performed in teams of two. Teams take measurements with these devices and fit their data to theory presented in the lecture. Devices covered include X-ray, CT, MRI, EEG, ECG, Ultrasound and BMI (Brain-machine interface). Prerequisites: BioE 103 or BioE 300B or EE 122B.
Same as: BIOE 201C

BIOE 301D. Microfluidic Device Laboratory. 3-4 Units.
This course exposes students to the design, fabrication, and testing of microfluidic devices for biological applications through combination of lectures and hands-on lab sessions. In teams of two, students will produce a working prototype devices designed to address specific design challenges within the biological community using photolithography, soft lithography, and imaging techniques.
Same as: GENE 207

BIOE 311. Biophysics of Multi-cellular Systems and Amorphous Computing. 2-3 Units.
Provides an interdisciplinary perspective on the design, emergent behavior, and functionality of multi-cellular biological systems such as embryos, biofilms, and artificial tissues and their conceptual relationship to amorphous computers. Students discuss relevant literature and introduced to and apply pertinent mathematical and biophysical modeling approaches to various aspect multi-cellular systems, furthermore carry out real biology experiments over the web. Specific topics include: (Morphogen) gradients; reaction-diffusion systems (Turing patterns); visco-elastic aspects and forces in tissues; morphogenesis; coordinated gene expression, genetic oscillators and synchrony; genetic networks; self-organization, noise, robustness, and evolvability; game theory; emergent behavior; criticality; symmetries; scaling; fractals; agent based modeling. The course is geared towards a broadly interested graduate and advanced undergraduates audience such as from bio / applied physics, computer science, developmental and systems biology, and bio / tissue / mechanical / electrical engineering. Prerequisites: Previous knowledge in one programming language - ideally Matlab - is recommended; undergraduate students benefit from BIOE 41, BIOE 42, or equivalent.
Same as: BIOE 211, BIOPHYS 311, DBIO 211

BIOE 313. Neuromorphics: Brains in Silicon. 3 Units.
(Formerly EE 304) Neuromorphic systems run perceptual, cognitive and motor tasks in real-time on a network of highly interconnected nonlinear units. To maximize density and minimize energy, these units--like the brain's neurons--are heterogeneous and stochastic. The first half of the course covers learning algorithms that automatically synthesize network configurations to perform a desired computation on a given heterogeneous neural substrate. The second half of the course surveys system-on-a-chip architectures that efficiently realize highly interconnected networks and mixed analog-digital circuit designs that implement area and energy-efficient nonlinear units. Prerequisites: EE102A is required.
Same as: EE 207

BIOE 326A. In Vivo MR: SpinPhysics and Spectroscopy. 3 Units.
Collections of independent identical nuclear spins are well described by the classical vector model of magnetic resonance imaging, however, interaction among spins, as occur in many in vivo processes, require a more complete description. This course develops the basic physics and engineering principles of these interactions with emphasis on current research questions and clinical spectroscopy applications. Prerequisite: EE396b; familiarity with MRI, linear algebra recommended.
Same as: RAD 226A

BIOE 326B. In Vivo MR: Relaxation Theory and Contrast Mechanisms. 3 Units.
Principles of nuclear magnetic resonance relaxation theory as applicable to in vivo processes with an emphasis on medical imaging. Topics: physics and mathematics of relaxation, relaxation times in normal and diseased tissues, magnetization transfer contrast, chemical exchange saturation transfer, MRI contrast agents, and hyperpolarized 13C. Prerequisites: BIOE 22A.
Same as: RAD 226B

BIOE 331. Protein Engineering. 3 Units.
The design and engineering of biomolecules emphasizing proteins, antibodies, and enzymes. Combinatorial and rational methodologies, protein structure and function, and biophysical analyses of modified biomolecules. Clinically relevant examples from the literature and biotech industry. Prerequisite: basic biochemistry. Winter, Cochran.
Same as: BIOE 231

BIOE 333. Interfacial Phenomena and Bionanotechnology. 3 Units.
Control over and understanding of interfacial phenomena and colloidal science are the essential foundation of bionanotechnology. Key mathematical relationships derived by Laplace, Gibbs, Kelvin and Young are derived and explained, along with the thermodynamics of systems of large interfacial area. Forces controlling surface and interfacial phenomena and surfactant and biomacromolecule self-assembly are discussed. Protein folding/unfolding and aggregation, and nano- and microfluidics are elucidated in these terms. Students will gain insight into the interplay between physical and chemical properties of biomolecules. Spring, (Barron, A.).

BIOE 334. Engineering Principles in Molecular Biology. 3 Units.
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.

BIOE 335. Molecular Motors I. 3 Units.
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.

BIOE 337. Organismic Biophysics and Living Soft-matter. 3 Units.
Integrated physical biology; from molecules to organisms. Tree of life, diversity of life forms. Multi-scale/hierarchical systems in biophysics, Hierarchical self-organization. Basic theory of squishy materials, colloidal physics. Phase transitions in living soft-matter. Experimental techniques in soft-matter physics. Active fluid models for living matter. Design of self-assembling and self-organizing, biomimetic supramolecular systems.

BIOE 355. Advanced Biochemical Engineering. 3 Units.
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 pharaceuticals 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.
Same as: CHEMENG 355

BIOE 361. Biomaterials in Regenerative Medicine. 3 Units.
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.
Same as: MATSCI 381

BIOE 370. Microfluidic Device Laboratory. 2 Units.
Fabrication of microfluidic devices for biological applications. Photolithography, soft lithography, and micromechanical valves and pumps. Emphasis is on device design, fabrication, and testing.

BIOE 371. Global Biodesign: Medical Technology in an International Context. 3 Units.
This course (BIOE 371, OIT 587, MED 271) examines the challenges and opportunities of developing and implementing innovative medical technologies to help patients around the world. Faculty and guest speakers discuss the status of the global health technology industry, as well as trends and issues affecting health technology innovation in seven primary geographic regions: Africa, China, Europe, India, Japan, Latin America, and the United States. Students explore key differences between the covered geographies, which range from emerging markets with vast bottom-of-the-pyramid and growing middle class populations, to well-established markets with sophisticated demands and shifting demographics. The course utilizes real-world case studies and class projects to promote engagement and provide a hands-on learning experience. Students work in multidisciplinary teams with real-world companies to develop a plan for bringing an existing product to a new global market. Teams will interact with representatives from their chosen company throughout the quarter, as well as with a faculty mentor, and present their recommendations at the conclusion of spring term.
Same as: MED 271

BIOE 372. Design for Service Innovation. 4 Units.
(Same as OIT 343/01) Open to graduate students from all schools and departments. An experiential project course in which students work in multidisciplinary teams to design new services to address the needs of medically patients. Project teams partner with "safety net" hospitals and clinics to find better ways to deliver care to the low income and uninsured patients these institutions serve. Students learn proven innovation processes from experienced GSB, d. school, and SoM faculty, interface with students from across the university, and have the opportunity to see their ideas translated into improvements in the quality and efficiency of healthcare in the real world. Prerequisite: admission to the course is by application only. Applications available at http://DesignForService.stanford.edu. Applications must be submitted by November 16, 2011.
Same as: HRP 274, MED 274

BIOE 374A. Biodesign Innovation: Needs Finding and Concept Creation. 4 Units.
In this two-quarter course series (BIOE 374A/B, MED 272A/B, ME 368A/B, OIT 384/5), multidisciplinary student teams identify real-world unmet healthcare needs, invent new medtech products to address them, and plan for their development into patient care. During the first quarter (winter 2017), students select and characterize an important unmet healthcare problem, validate it through primary interviews and secondary research, and then brainstorm and screen initial technology-based solutions. In the second quarter (spring 2017), teams select a lead solution and move it toward the market through prototyping, technical re-risking, strategies to address healthcare-specific requirements (regulation, reimbursement), and business planning. Final presentations in winter and spring are made to a panel of prominent medtech experts and investors. Class sessions include faculty-led instruction and case demonstrations, coaching sessions by industry specialists, expert guest lecturers, and interactive team meetings. Enrollment is by application only, and students are expected to participate in both quarters of the course. Visit http://biodesign.stanford.edu/programs/stanford-courses/biodesign-innovation.html to access the application, examples of past projects, and student testimonials. More information about Stanford Biodesign, which has led to the creation of more than 40 venture-backed healthcare companies and has helped hundreds of student launch health technology careers, can be found at http://biodesign.stanford.edu/.
Same as: ME 368A, MED 272A

BIOE 374B. Biodesign Innovation: Concept Development and Implementation. 4 Units.
In this two-quarter course series (BIOE 374A/B, MED 272A/B, ME 368A/B, OIT 384/5), multidisciplinary student teams identify real-world unmet healthcare needs, invent new medtech products to address them, and plan for their development into patient care. During the first quarter (winter 2017), students select and characterize an important unmet healthcare problem, validate it through primary interviews and secondary research, and then brainstorm and screen initial technology-based solutions. In the second quarter (spring 2017), teams select a lead solution and move it toward the market through prototyping, technical re-risking, strategies to address healthcare-specific requirements (regulation, reimbursement), and business planning. Final presentations in winter and spring are made to a panel of prominent medtech experts and investors. Class sessions include faculty-led instruction and case demonstrations, coaching sessions by industry specialists, expert guest lecturers, and interactive team meetings. Enrollment is by application only, and students are expected to participate in both quarters of the course. Visit http://biodesign.stanford.edu/programs/stanford-courses/biodesign-innovation.html to access the application, examples of past projects, and student testimonials. More information about Stanford Biodesign, which has led to the creation of more than 40 venture-backed healthcare companies and has helped hundreds of student launch health technology careers, can be found at http://biodesign.stanford.edu/.
Same as: ME 368B, MED 272B

BIOE 375A. Biodesign Innovation: Needs Finding and Concept Creation. 2 Units.
Enrollment limited to SCPD students. 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.

BIOE 375B. Biodesign Innovation: Concept Development and Implementation. 2 Units.
Enrollment limited to SCPD students. 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. Prerequisite: BIOE 375A.

BIOE 376. Startup Garage: Design. 4 Units.
A hands-on, project-based course, in which teams identify and work with users, domain experts, and industry participants to identify an unmet customer need, design new products or services that meet that need, and develop business models to support the creation and launch of startup products or services. This course integrates methods from human-centered design, lean startup, and business model planning. Each team will conceive, design, build, and field-test critical aspects of both the product or service and the business model.

BIOE 377. Startup Garage: Testing and Launch. 4 Units.
STRAMGT 356/BIOE 376 teams that concluded at the end of fall quarter that their preliminary product or service and business model suggest a path to viability, may continue with STRAMGT 366/BIOE 377 in winter quarter. Teams develop more elaborate versions of their product/service and business model, perform a series of experiments to test key hypotheses about their product and business model, and prepare and present an investor pitch for a seed round of financing to a panel of seasoned investors and entrepreneurs.

BIOE 381. Orthopaedic Bioengineering. 3 Units.
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.
Same as: ME 381

BIOE 386. Neuromuscular Biomechanics. 3 Units.
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.
Same as: ME 386

BIOE 390. Introduction to Bioengineering Research. 1-2 Unit.
Preference to medical and bioengineering graduate students with first preference given to Bioengineering Scholarly Concentration medical 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. Students and faculty make presentations during the course. Students expected to make presentations, complete a short paper, read selected articles, and take quizzes on the material.
Same as: MED 289

BIOE 391. Directed Study. 1-6 Unit.
May be used to prepare for research during a later quarter in 392. Faculty sponsor required. May be repeated for credit.

BIOE 392. Directed Investigation. 1-10 Unit.
For Bioengineering graduate students. Previous work in 391 may be required for background; faculty sponsor required. May be repeated for credit.

BIOE 393. Bioengineering Departmental Research Colloquium. 1 Unit.
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. Aut, Win, Spr (Lin, Riedel-Kruse, Barron).

BIOE 450. Advances in Biotechnology. 3 Units.
Overview of cutting edge advances in biotechnology with a focus on therapeutic and health-related topics. Academic and industrial speakers from fields including protein engineering, immuno-oncology, DNA sequencing, the microbiome, diagnostics, synthetic biology, and more. Biotechnology business topics such as entrepreneurship, venture capital, and intellectual property will also be covered. Course is designed for students interested in pursuing a career in the biotech industry.
Same as: CHEMENG 450

BIOE 454. Synthetic Biology and Metabolic Engineering. 3 Units.
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.
Same as: CHEMENG 454

BIOE 459. Frontiers in Interdisciplinary Biosciences. 1 Unit.
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.
Same as: BIO 459, BIOC 459, CHEM 459, CHEMENG 459, PSYCH 459

BIOE 484. Computational Methods in Cardiovascular Bioengineering. 3 Units.
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.
Same as: ME 484

BIOE 485. Modeling and Simulation of Human Movement. 3 Units.
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.
Same as: ME 485

BIOE 500. Thesis. 1-15 Unit.
(Staff).
Same as: Ph.D.

BIOE 802. TGR Dissertation. 0 Units.
(Staff).