

# BIOENGINEERING

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Courses given in Bioengineering have the subject code BIOE. For a complete list of subject codes, see Appendix.

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

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

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

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

## UNDERGRADUATE PROGRAMS

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

## COTERMINAL B.S./M.S. PROGRAM

This option is available to outstanding Stanford undergraduates who wish to work simultaneously toward a B.S. in another field and an M.S. in Bioengineering. The degrees may be granted simultaneously or at the

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

The application must provide evidence of potential for strong academic performance as a graduate student. The application is evaluated and acted 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.

## GRADUATE PROGRAMS

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

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

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

The deadline for receiving applications is January 8, 2008.

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

## MASTER OF SCIENCE

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

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

1. Core *Bioengineering courses* (9 units); the following courses are required:

- BIOE 300A. Molecular and Cellular Bioengineering
- BIOE 300B. Quantitative Mammalian Physiology and Tissue Engineering
- BIOE 301A. Molecular and Cellular Bioengineering Lab
- BIOE 301B. Clinical Needs and Technology

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

2. *Approved Technical Electives* (27 units): these units must be selected from graduate courses in mathematics, statistics, engineering, physical science, life science, and medicine. They should be chosen in concert with the bioengineering courses to provide a cohesive degree program in a bioengineering focus area. Students are required to take at least one course in some area of design or instrumentation. Up to 9 units of directed study and research may be used as approved electives.
3. *Seminars* (3 units): the seminar units should be fulfilled through BIOE 390, Introduction to Bioengineering Research, BIOE 393, Bioengineering Forum, or BIOE 459, Frontiers in Interdisciplinary Biosciences. Other relevant seminar units may also be used with the approval of the faculty adviser. One of the seminar units must be MED 255, The Responsible Conduct of Research.
4. *Unrestricted Electives* (6 units).

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

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

## DOCTOR OF PHILOSOPHY

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.

## 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.

## COURSES

### STANFORD INTRODUCTORY SEMINARS

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

*3 units, Spr (Doshi, R; Mandato, J)*

### ADVANCED UNDERGRADUATE AND GRADUATE

**BIOE 191. Bioengineering Problems and Experimental Investigation**—Directed study and research for undergraduates on a subject of mutual interest to student and instructor. Prerequisites: consent of instructor and adviser.

*1-5 units, Aut, Win, Spr, Sum (Staff)*

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

3 units, Aut (Altman, R; Cheng, B; Klein, T)

**BIOE 214. Representations and Algorithms for Computational Molecular Biology**—(Same as BIOMEDIN 214, CS 274, GENE 214.) Topics: algorithms for alignment of biological sequences and structures, computing with strings, phylogenetic tree construction, hidden Markov models, computing with networks of genes, 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, graphical display of biological data, machine learning (clustering and classification), and natural language text processing. Prerequisites: programming skills; consent of instructor for 3 units.

3-4 units, Spr (Altman, R)

**BIOE 215. Physics-Based Simulation of Biological Structure**—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.

3 units, Spr (Altman, R; Delp, S; Mitiguy, P)

**BIOE 220. Imaging Anatomy**—(Same as RAD 220.) The physics of medical imaging and human anatomy through medical images. Emphasis is on normal anatomy, contrast mechanisms, and the relative strengths of each imaging modality. Labs reinforce imaging techniques and anatomy. Recommended: basic biology, physics.

3 units, Win (Gold, G; Butts-Pauly, K)

**BIOE 222A. Multimodality Molecular Imaging in Living Subjects I**—(Same as RAD 222A.) Instruments for imaging molecular and cellular events in animals and human beings using novel assays. Instrumentation physics, chemistry of molecular imaging probes, and applications to preclinical models and clinical disease management.

4 units, Aut (Gambhir, S; Rao, J)

**BIOE 222B. Multimodality Molecular Imaging in Living Subjects II**—(Same as RAD 222B.) In vivo imaging techniques and applications to preclinical models and clinical disease management. Focus on cancer research, neurobiology, cardiovascular and musculoskeletal diseases.

4 units, Win (Gambhir, S; Rao, J)

**BIOE 261. Principles and Practice of Stem Cell Engineering**—(Same as NSUR 261.) Quantitative models used to characterize incorporation of new cells into existing tissues emphasizing pluripotent cells such as embryonic and neural stem cells. Molecular methods to control stem cell decisions to self-renew, differentiate, die, or become quiescent. Practical, industrial, and ethical aspects of stem cell technology application. Final projects: team-reviewed grants and business proposals.

3 units, Aut (Deisseroth, K; Palmer, T)

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

3 units, Aut (Delp, S)

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

3 units, Aut (Taylor, C)

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

3 units, Win (Taylor, C)

## GRADUATE

**BIOE 300A. Molecular and Cellular Bioengineering**—(Formerly 200A.) The molecular and cellular bases of life from an engineering perspective. Quantitative analysis and engineering of biomolecular structure and dynamics, enzyme function, molecular interactions, metabolic pathways, signal transduction, and cellular mechanics. Required: course work in biochemistry and thermodynamics.

3 units, Win (Bryant, Z)

**BIOE 300B. Quantitative Mammalian Physiology and Tissue Engineering**—(Formerly 200B.) The interaction, communication, and disorders of major organ systems and relevant developmental biology and tissue engineering from cells to complex organs.

3 units, Spr (Deisseroth, K; Covert, M)

**BIOE 301A. Molecular and Cellular Bioengineering Lab**—(Formerly 201A.) Preference to Bioengineering graduate students. Practical applications of biotechnology and molecular bioengineering including recombinant DNA techniques, molecular cloning, microbial cell growth and manipulation, library screening, and microarrays. Emphasis is on experimental design and data analysis. Limited enrollment. Corequisite: 300A.

2 units, Win (Cochran, J)

**BIOE 301B. Clinical Needs and Technology**—(Formerly 201B.) Diagnostic and therapeutic methods employed in medicine. Each student paired with a physician. Labs include a pathology/histology session, pulmonary function testing, and the Goodman Simulation Center. Clinical experience, chosen from 12 specialties, includes observation of an operation or procedure. Final paper. Limited enrollment. Corequisite: 300B.

1 unit, Spr (Feinstein, J)

**BIOE 310. Dynamic Models in Biology**—How to use the power of computational modeling in biological research. Biological problems including population dynamics, membrane currents, cellular dynamics, the spread of infectious disease, and spatial pattern formation. Key modeling approaches such as linear systems of differential equations, stochastic models, network models, and agent-based models. Matlab tutorial.

3 units, not given this year (Covert, M)

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

3 units, alternate years, not given this year (Cochran, J)

**BIOE 332A,B. Large-Scale Neural Modeling**—Emphasis is on cortical computation, from feature maps in the neocortex to episodic memory in the hippocampus, with attention to the roles of recurrent connectivity, rhythmic activity, spike synchrony, synaptic plasticity, and noise and heterogeneity. Large-scale models run in real-time on neuromorphic hardware developed for this purpose. Techniques to analyze and predict network behavior; applications to data recorded from models in laboratory. Techniques introduced are used to develop projects in second half of two-quarter sequence.

3 units, **A: Win, B: Spr** (Boahen, K)

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

3 units, *Spr* (Swartz, J)

**BIOE 361. Biomaterials in Regenerative Medicine**—(Same as MATSCI 381.) How materials interact with cells through their micro- and nanostructure, mechanical properties, degradation characteristics, surface chemistry, and biochemistry. Examples include novel materials for drug and gene delivery, materials for stem cell proliferation and differentiation, and tissue engineering scaffolds. Prerequisites: undergraduate chemistry, and cell/molecular biology or biochemistry.

3 units, *Win* (Heilshorn, S; Cochran, J)

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

2 units, *Win* (Quake, S; Gomez-Sjoberg, R), *Spr* (Quake, S)

**BIOE 374A. Biodesign Innovation: Needs Finding and Concept Creation**—(Same as OIT 384, ME 374A, MED 272A.) Two quarter sequence. Strategies for interpreting clinical needs, researching literature, and searching patents. Clinical and scientific literature review, techniques of intellectual property analysis and feasibility, basic prototyping, and market assessment. Student entrepreneurial teams create, analyze, and screen medical technology ideas, and select projects for development.

3-4 units, *Win* (Yock, P; Brinton, T; Zenios, S; Milroy, C)

**BIOE 374B. Biodesign Innovation: Concept Development and Implementation**—(Same as OIT 385, ME 374B, MED 272B.) Two quarter sequence. Concept development and implementation. Early factors for success; how to prototype inventions and refine intellectual property. Lectures, guest medical pioneers, and entrepreneurs about strategic planning, ethical considerations, new venture management, and financing and licensing strategies. Cash requirements; regulatory (FDA), reimbursement, clinical, and legal strategies, and business or research plans.

3-4 units, *Spr* (Yock, P; Brinton, T; Zenios, S; Milroy, C)

**BIOE 386. Neuromuscular Biomechanics**—(Same as ME 386.) The interplay between mechanics and neural control of movement. State of the art assessment through a review of classic and recent journal articles. Emphasis is on the application of dynamics and control to the design of assistive technology for persons with movement disorders.

3 units, *not given this year* (Delp, S)

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

1-2 units, *Aut, Win* (Taylor, C)

**BIOE 391. Directed Study**—May be used to prepare for research during a later quarter in 392. Faculty sponsor required. May be repeated for credit.

1-6 units, *Aut, Win, Spr, Sum* (Staff)

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

1-10 units, *Aut* (Staff), *Win* (Block, S), *Spr, Sum* (Staff)

**BIOE 393. Bioengineering and Biodesign Forum**—(Same as ME 389) Guest speakers present research topics at the interfaces of biology, medicine, physics, and engineering. May be repeated for credit.

1 unit, *Aut, Win, Spr* (Altman, R)

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

3 units, *alternate years, not given this year*

**BIOE 459. Frontiers in Interdisciplinary Biosciences**—(Crosslisted in departments in the schools of H&S, Engineering, and Medicine; 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://www.stanford.edu/group/biox/courses/459.html>. Recommended: basic mathematics, biology, chemistry, and physics.

1 unit, *Aut, Win, Spr* (Robertson, C)

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

3 units, *alternate years, not given this year* (Taylor, C)

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

3 units, *Spr* (Delp, S)

**BIOE 500. Thesis (Ph.D.)**

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

**COGNATE COURSES**

See respective department listings for course descriptions and General Education Requirements (GER) information. See degree requirements above or the program's student services office for applicability of these courses to a major or minor program.

**BIOC 218. Computational Molecular Biology**—(Same as BIOMEDIN 231.)

3 units, Aut (Staff), Win, Spr (Brutlag, D)

**BIOMEDIN 210. Introduction to Biomedical Informatics: Fundamental Methods**—(Same as CS 270.)

3 units, Aut (Musen, M)

**BIOMEDIN 217. Translational Bioinformatics**—(Same as CS 275.)

4 units, Win (Butte, A; Hillenmeyer, M; Southworth, L)

**CHEMENG 450. Advances in Biotechnology**

3 units, Spr (Hwang, L; Swartz, J)

**EE 369A. Medical Imaging Systems I**

3 units, not given this year

**EE 369B. Medical Imaging Systems II**

3 units, Spr (Nishimura, D)

**EE 369C. Medical Image Reconstruction**

3 units, Aut (Pauly, J)

**ME 280. Skeletal Development and Evolution**

3 units, Spr (Carter, D)

**ME 287. Soft Tissue Mechanics**

3 units, Aut (Levenston, M)

**ME 381. Orthopaedic Bioengineering**

3 units, Aut (Carter, D)

**ME 382A. Medical Device Design**

4 units, Win (Andriacchi, T)

**ME 382B. Medical Device Design**

4 units, Spr (Andriacchi, T)

**ME 385. Tissue Engineering Lab**

1-2 units, Win (Jacobs, C)

**RAD 226. In Vivo Magnetic Resonance Spectroscopy and Imaging**

3 units, Win (Spielman, D)

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