Bioengineering

STUDENT AFFAIRS:
141 Powell-Focht Bioengineering Hall,
Warren College
http://www-bioeng.ucsd.edu/homepage.html

Professors

S. Chien, M.D., Ph.D., *Chair, Director, Whitaker Institute for Biomedical Engineering*
Y. C. Fung, Ph.D., *Professor Emeritus*
W. R. Giles, Ph.D.
D. A. Gough, Ph.D.
M. J. Heller, Ph.D.
M. Intaglietta, Ph.D.
A. D. McCulloch, Ph.D., *Vice Chair*
B. O. Palsson, Ph.D.
R. L. Sah, M.D., Sc.D., *Vice Chair*
G. W. Schmid-Schoenbein, Ph.D.
S. Subramaniam, Ph.D.
J. T. Watson, Ph.D., *(In-Residence)*

Associate Professors

S. N. Bhatia, M.D., Ph.D.
L. A. Sung, Ph.D.

Assistant Professors

J. M. Hasty, Ph.D.
X. Huang, Ph.D.
G. A. Huber, Ph.D.
T. G. Ideker, Ph.D.
G. A. Silva, Ph.D. *(In-Residence)*

Adjunct Professors

M. W. Berns, Ph.D.
L. M. Bjursten, Ph.D.
C. R. Cantor, Ph.D.
J. A. Frangos, Ph.D.
D. J. Galas, Ph.D.
T. E. Hugli, Ph.D.
P. C. Johnson, Ph.D.
E. I. Ruoslahti, M.D., Ph.D.
P. Tong, Ph.D.
R. M. Winslow, Ph.D.

Assistant Adjunct Professor

D. A. MacKenna, Ph.D.

Affiliated Faculty

P. C. Chau, Ph.D., *Professor, Mechanical and Aerospace Engineering*
K. R. Chien, Ph.D., *Professor, Medicine*
J. W. Covell, M.D., *Professor Emeritus, Medicine*
M. H. Ellisman, Ph.D., *Professor, Neurosciences*
A. Fronek, M.D., Ph.D., *Professor Emeritus, Surgery*
R. L. Lieber, Ph.D., *Professor, Orthopaedics*
J. H. Omens, Ph.D., *Associate Adjunct Professor, Medicine*
K. L. P. Sung, Ph.D., *Professor In-Residence, Orthopaedics*
P. D. Wagner, M.D., *Professor, Medicine*
J. B. West, M.D., Ph.D., *Professor, Medicine*

Professional Research Staff

D. A. Baker, Ph.D., *Associate Research Scientist*
A. C. Chen, Ph.D., *Assistant Project Scientist*
P. C. Chen, Ph.D., *Associate Project Scientist*
S. Fukuda, Ph.D., *Assistant Project Scientist*
Y. L. Hu, Ph.D., *Assistant Project Scientist*
W. Huang, M.D., Ph.D., *Associate Project Scientist*
Y. S. Li, Ph.D., *Associate Project Scientist*
D. Lim, Ph.D., Sc.D., *Research Scientist*
M. T. Makale, Ph.D., *Associate Project Scientist*
H. Miao, Ph.D., *Assistant Project Scientist*
A. P. Mihaylova, Ph.D., *Assistant Research Scientist*
J. H. Price, M.D., Ph.D., *Associate Research Scientist*
A. G. Tsai, Ph.D., *Associate Research Scientist*
S. Usami, M.D., Ph.D., *Research Scientist*
T. Usyk, Ph.D., *Assistant Project Scientist*
N. Wang, M.D., *Assistant Research Scientist*
Y. H. Zhao, Ph.D., *Assistant Project Scientist*

Departmental Focus

Bioengineering is an interdisciplinary major in which the principles and tools of traditional engineering fields, such as mechanical, materials, electrical, and chemical engineering, are applied to biomedical problems. Engineering plays an increasingly important role in medicine in projects that range from basic research in physiology to advances in biotechnology and the improvement of health care delivery. By its very nature, bioengineering is broad and requires a foundation in the engineering sciences as well as in physiology and other biological sciences.

The overall mission of the Department of Bioengineering is to provide students with an education that enables successful, innovative, and lifelong careers in bioengineering industries and professions, including

- depth, breadth, and creativity in the central areas of bioengineering, its underlying mathematical, physical and biological sciences, and related technologies
- effective communication, learning, and teamwork skills that facilitate bioengineering practice, continued professional advancement, and adaptation
- a recognition of professional and social responsibilities, including sensitivity to ethical and health-related issues

At the undergraduate level, the department offers several four-year engineering majors. One leads to a **B.S. degree in Bioengineering**. This major prepares students for careers in the biomedical industry and for further education in graduate school. Students completing the B.S. degree in Bioengineering have sufficient preparation to be employed in traditional engineering areas other than the biomedical industry, if they wish. This program addresses the bioengineering topics of biomechanics, biotransport, bioinstrumentation, bioelectricity, biosystems, and biomaterials, and the complementary fields of systems and organ-level physiology. Education in these areas allows application of bioengineering and scientific principles to the development of medical devices and technologies that benefit human health by advancing methods for effective diagnosis and treatment of disease. The bioengineering program is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (EAC/ABET).

The department also offers a **B.S. degree in Bioengineering: Biotechnology**. This is a four-year engineering curriculum that prepares students for careers in the biotechnology industry and for further education in graduate school. The curriculum has a strong engineering foundation with emphasis on biochemical process applications. This program addresses the bioengineering topics of biochemistry and metabolism, kinetics, biotransport, biosystems, bioreactors, bioseparations, tissue engineering, and the complementary fields of cellular physiology. Education in these areas allows application of bioengineering and physicochemical principles to cellular and molecular biology, with the applications that benefit human health. The Bioengineering: Biotechnology program is accredited by EAC/ABET.

In addition, the department offers a four-year major leading to a **B.S. degree in Bioengineering: Premedical**. This curriculum is designed to meet the requirements for admission to medical schools and is also suitable for those planning to enter graduate school in bioengineering,

physiology, neurosciences, or related fields. This program provides a quantitative understanding of the engineering design of the body, as well as certain technologies used in medical practice. It has less engineering content but more biological sciences and is one of many majors that can serve as preparation for further training in medical, veterinary, or allied health professions. Some graduates of this program also go on to work in industry.

The department also offers a major leading to a **B.S. degree in Bioengineering: Bioinformatics**. Bioinformatics is the study of the flow of information (genetic, metabolic, and regulatory) in living systems to provide an understanding of the properties of cells and organisms. This major has been developed by the Departments of Bioengineering, Chemistry and Biochemistry, Computer Science and Engineering, and the Division of Biology. Students wishing to major in bioinformatics may apply through any of these departments or the division. The Bioinformatics major in Bioengineering emphasizes systems engineering and model-based approaches to interpreting and integrating bioinformatics data. The Bioinformatics major prepares students for careers in the pharmaceutical, biotechnology, and biomedical software industries, and for further studies in graduate school.

The programs and curricula of bioengineering emphasize education in the fundamentals of engineering sciences that form the common basis of all engineering subspecialties. Education with this emphasis is intended to provide students with a solid engineering foundation for a career in which engineering practice may change rapidly. In addition, elements of bioengineering design are incorporated at every level in the curricula. This is accomplished by integration of laboratory experimentation, computer applications, and exposure to real bioengineering problems throughout the program. Students also work as teams in senior design project courses to solve multidisciplinary bioengineering problems suggested by industrial and clinical experience.

At the graduate level, specialized curricula lead to the **M.S., M.Eng. (Master of Engineering),** and **Ph.D.** degrees, as well as an integrated **B.S./M.S.** degree. In addition to the Ph.D. degree, the department offers a **Ph.D. degree with a specialization in Bioinformatics.** It is intended for students who have an interdisciplinary persuasion to work across computers, biology, medicine, and engineering. Bioinformatics characterizes the flow of information in living systems. For further information on the specialization please consult with the Student Affairs Office. There are also **M.D./M.S., M.D./M.Eng.** and **M.D./Ph.D.** degrees offered in conjunction with UCSD Medical School, pending independent admission to the Medical School. The M.Eng. degree is a terminal professional degree whereas the M.S. and Ph.D. degrees are research programs. *(See section on master's degree programs.)* The graduate programs are characterized by strong interdisciplinary relationships with the other engineering departments and Departments of Physics, Mathematics, Biology, Chemistry and Biochemistry, Medicine, and others, as well as with campus organizations such as the Whitaker Institute for Biomedical Engineering, Institute for Mechanics and Materials, and the School of Medicine.

The Undergraduate Program

Major Requirements

Specific course requirements for each of the majors are outlined in tables below. In addition to the required technical courses specifically indicated, a suggested scheduling of humanities and social science courses (HSS) are included in the curricula for students to use to meet college general-education requirements. To graduate, students must maintain an overall GPA of at least 2.0, and obtain at least a C– grade in each course required for the major. All courses required for the major must be taken for a letter grade.

Deviations from the required programs of study must be approved by the Undergraduate Studies Committee *prior* to taking alternative courses. In addition, students must obtain departmental approval of technical elective (TE) course selections *prior* to taking the course. In the ABET-accredited programs, TE courses are restricted to those that meet ABET standards. Courses such as Bioengineering 196, 197, and 198 are encouraged, but they do not count as upper-division technical electives. Bioengineering 195 and 199 can be used as technical electives under certain conditions. Policy information may be obtained from the Student Affairs Office.

Students with accelerated academic preparation at admission to the university may vary the scheduling of lower-division courses such as mathematics, physics, and chemistry, but must first consult the department. Most lower-division courses are offered more than once each year to permit students some flexibility in their program scheduling. However, most Bioengineering upper-division courses are taught only once each year. **Deviations in the scheduling of upper-division bioengineering courses are strongly discouraged, as such changes usually lead to a delay in graduation.** The curricula shown in the tables below are consistent with the current scheduling of classes.

Minors are not offered in bioengineering, and double major options are restricted. Students interested in double majors should consult the Student Affairs Office as early as possible.

General-Education/ College Requirements

For graduation, each student must satisfy general-education course requirements determined by the student's college, as well as the major requirements determined by the department. The six colleges at UCSD require different general-education courses, and the number of such courses differs from one college to another. Each student should choose his or her college carefully, considering the special nature of the curriculum and the breadth of general education.

The bioengineering programs allow for humanities and social science (HSS) courses so that students can fulfill their college requirements. In the bioengineering ABET-accredited programs, students must develop a program that includes a total of at least twenty-four units in the arts, humanities, and social sciences, not including subjects such as accounting, industrial management, finance, or personnel administration. It should be noted, however, that some colleges require more than the ten HSS courses indicated in the *Bioengineering, Bioengineering: Biotechnology, and Bioengineering: Bioinformatics* curriculum tables. Accordingly, students in these colleges may take longer to graduate than the four years, indicated in the schedule. Students must consult with their colleges to determine which HSS courses to take.

BIOENGINEERING
(ABET-Accredited Program)

FALL	WINTER	SPRING
FRESHMAN YEAR		
Math. 20A	Math. 20B	Math. 20C
Chem. 6A	Chem. 6B	BILD 1
MAE 9 or 10	Phys. 2A	Phys. 2B/2BL
HSS[4]	BENG 1[2]	Chem. 6BL[1]
	HSS[4]	HSS[4]

SOPHOMORE YEAR		
Math. 20D	Math. 20F	Math. 20E
MAE 130A/SE 101A	MAE 140	MAE 3
Phys. 2C/2CL	BENG 106B	BENG 100
HSS[4]	HSS[4]	HSS[4]
JUNIOR YEAR		
BENG 101	BENG 112A	BENG 112B
BENG 110	BENG 186B	BENG 172
MAE 170	BENG 140A	BENG 140B
HSS[4]	HSS[4]	BENG 103B
SENIOR YEAR		
BENG 186A	BENG 122A	BENG 125
MAE 105	BENG 130	BENG 186C
HSS[4]	MAE 150	TE[3]
	TE[3]	HSS[4]
	BENG 191[5]	

[1] Chem. 6BL may be taken in any quarter within the first two years after completion of Chem. 6B.

[2] BENG 1 may be taken in sophomore year.

[3] Technical electives (TE) courses must be selected from a departmental approved list. Consult the Student Affairs Office.

[4] Ten HSS courses are listed here; individual college requirements may be higher.

[5] Recommended course, not required. For graduating seniors only.

BIOENGINEERING: BIOTECHNOLOGY *(ABET-Accredited Program)*

FALL	WINTER	SPRING
FRESHMAN YEAR		
Math. 20A	Math. 20B	Math. 20C
Chem. 6A	Chem. 6B	Chem. 6BL[1]/6C
MAE 9 or 10	Phys. 2A	Phys. 2B
HSS[4]	BENG 1[2]	HSS[4]
	HSS[4]	
SOPHOMORE YEAR		
Math. 20D	Math. 20F	Math. 20E
Chem. 140A	Phys. 2C/2CL	Chem. 140B
BILD 1	BENG 130	BENG 100
HSS[4]	HSS[4]	HSS[4]
JUNIOR YEAR		
BIBC 100	BIBC 102	BIBC 103
CENG 101A	BICD 100	BENG 103B
MAE 140	BENG 123	BENG 168
HSS[4]	HSS[4]	HSS[4]
SENIOR YEAR		
BENG 161A	BENG 161B	BENG 125
BENG 166A	BENG 162	BENG 161C
BENG 186A	BENG 191[5]	BENG 164
MAE 170	TE[3]	TE[3]
	HSS[4]	

[1] Chem. 6BL may be taken concurrently with Chem. 6C or in any quarter within the first two years after completion of Chem. 6B.

[2] BENG 1 may be taken in sophomore year.

[3] Technical electives (TE) courses must be selected from a departmental approved list. Consult the Student Affairs Office.

[4] Ten HSS courses are listed here; individual college requirements may be higher.

[5] Recommended course, not required. For graduating seniors only.

BIOENGINEERING: PREMEDICAL

FALL	WINTER	SPRING
FRESHMAN YEAR		
Math. 20A*	Math. 20B*	Math. 20C*
Chem. 6A*	Chem. 6B	Chem. 6BL[1]/6C
MAE 9 or 10*	Phys. 2A*	Phys. 2B*/2BL
HSS[4]	BENG 1[2]	HSS[4]
	HSS[4]	
SOPHOMORE YEAR		
Math. 20D	Math. 20F	Math. 20E
BILD 1	BILD 2	BENG 100
Phys. 2C/2CL	Chem. 140A	Chem. 140B
HSS[4]	HSS[4]	HSS[4]
JUNIOR YEAR		
BENG 110	BENG 112A	BENG 112B
Chem. 140C[5]	BICD 100	BIBC 100
Chem. 143A	MAE 140	MAE 170
HSS[4]	HSS[4]	HSS[4]
SENIOR YEAR		
BENG 186A	BENG 186B	BENG 172
BIPN 140	BIPN 100	BIPN 102
TE[3]	TE[3]	TE[3]
HSS[4]	HSS[4]	HSS[4]

* Seven of the eight courses used to compute the performance index upon which Pre-Bioengineering: Premedical majors are admitted to the major at the end of the freshman year. The other course must be in engineering, science, or mathematics.

[1] Chem. 6BL may be taken concurrently with Chem. 6C or in any quarter within the first two years after completion of Chem. 6B.

[2] BENG 1 may be taken in sophomore year.

[3] Technical electives (TE) courses must be selected from a departmental approved list. Consult the Student Affairs Office.

[4] Twelve HSS courses are listed here; individual college requirements may be higher.

[5] Chem. 140C is not required for the major and can be used as a technical elective. Chem. 140C is a requirement for application to most medical schools.

BIOENGINEERING: BIOINFORMATICS

FALL	WINTER	SPRING
FRESHMAN YEAR		
BILD 3	BILD 1	BILD 2
Chem. 6A	Chem. 6B	BILD 94
Math. 20A	Math. 20B	Chem. 6BL[1]/6C
HSS[4]	HSS[4]	Math. 20C
		HSS[4]
SOPHOMORE YEAR		
CSE 11[2]	CSE 12	CSE 21/ Math. 15B
Math. 20D	Chem. 140A	Chem. 140B
Phys. 2A	Phys. 2B	Phys. 2C
HSS[4]	HSS[4]	HSS[4]
JUNIOR YEAR		
BICD 102/Chem. 114B	BIMM 100/ Chem. 114C	BICD 110
BICD 100	CSE 101/ Math. 188	BIMM 101/ Chem. 112B
CSE 100/Math. 176	CSE 101/ Math. 20F	BENG 181
Phys. 140A	Math. 186	HSS[4]
SENIOR YEAR		
BENG 182	BENG 130	BENG 161C
BENG 183	BENG 184	BIMM 185
BIBC 103	TE[3]	HSS[4]
HSS[4]	HSS[4]	

[1] Chem 6BL may be taken concurrently with Chem. 6C or in any quarter within the first two years after completion of Chem 6B.

[2] Students may take the slower paced version, CSE 8A-B, instead of CSE 11.

[3] Technical elective (TE) courses must be selected from a departmental approved list. Consult the Student Affairs Office.

[4] Ten HSS courses are listed here; individual college requirements may be higher.

Policies and Procedures

Transfer Student Admission into Bioengineering, Bioengineering: Biotechnology, Bioengineering: Premedical, or Bioengineering: Bioinformatics

Effective **fall 2004**, it is **strongly recommended** that transfer students complete the following preparation for engineering majors*:

- Calculus I—for Science and Engineering (Math. 20A)
- Calculus II—for Science and Engineering (Math. 20B)
- Calculus and Analytic Geometry (Math. 20C)
- Differential Equations (Math. 20D)
- Linear Algebra (Math. 20F)
- Complete calculus-based physics series with lab experience (Physics 2A-B-C)
- Chemistry 6A (except Computer Science and Computer Engineering majors)
- Highest level of introductory computer programming language course offerings at the community college**

*Effective **fall 2006**, these courses will be **required** preparation for all engineering transfer students.

**Refer to the *UCSD General Catalog* to select major prerequisite requirement for computer language courses.

ADMISSION TO BIOENGINEERING OR BIOENGINEERING: BIOTECHNOLOGY

Because of heavy student interest in the Bioengineering and Bioengineering: Biotechnology majors, and the limited resources available to accommodate this demand, maintenance of a high quality program makes it necessary to limit enrollments to the most qualified students.

Freshman Students

Freshman students who have excelled in high school and have declared Bioengineering or Bioengineering: Biotechnology on their UCSD application are eligible for direct admission into those majors. These students will be notified directly by the Jacobs School of Engineering whether they have been admitted into their chosen major, based on admissions criteria and their ranking in the applicant pool. The only way for a student to become a Bioengineering or Bioengineering: Biotechnology major after enrolling as a freshman at UCSD is to be directly admitted at the time of entrance into UCSD.

Transfer Students

Admission of transfer applicants into Bioengineering or Bioengineering: Biotechnology is limited to those who have demonstrated a high level of achievement commensurate with the prospect of success in these majors. Successful applicants must have completed substantial training at the community college and must have achieved a high level of academic performance there. The required minimum of ninety quarter transfer units must include eighteen quarter-units of calculus, twelve quarter-units of calculus-based physics, and the highest level computer science course offered at their community college. Beginning fall 2006, ten quarter units of general chemistry (including laboratory), will be part of the required transfer units.

Applicants seeking admission as transfer students will be considered for direct admission into the Bioengineering and Bioengineering: Biotechnology majors in the Department of Bioengineering. The only way to become a Bioengineering or Bioengineering: Biotechnology major is to be directly admitted as an entering transfer student. Although the actual required GPA cutoff depends on the number of openings, at least a 3.2 GPA in the community college transfer courses, and a 3.4 GPA in math, physics, and computer science courses, are likely to be needed to gain admission.

ADMISSION TO BIOENGINEERING: PREMEDICAL

Freshman Students

Students intending to complete a Bioengineering: Premedical major are initially identified as Pre-Bioengineering: Premedical majors and admitted into a pre-major status. Pre-Bioengineering: Premedical majors who have achieved a GPA of 3.0 or better in the eight required pre-major courses (Mathematics 20A-B-C; Physics 2A-B; Chemistry 6A; MAE 9 or 10, and one other pre-bioengineering course by the end of the freshman year) are assured of admission into the Bioengineering: Premedical major. Students who have not completed the pre-major courses or achieved the necessary GPA for entry into the Bioengineering: Premedical major by the end of the freshman year may still enter the Bioengineering: Premedical major if these requirements have been satisfied before the end of the sixth quarter of study at UCSD. Students need to contact the Student Affairs Office at the end of the appropriate quarter to check on their status and complete an Undergraduate Change of Major Request form. Pre-Bioengineering: Premedical majors not admitted into the Bioengineering: Premedical major by the end of the sixth quarter of study at UCSD will automatically have their major converted from "Pre-Bioengineering: Premedical" to "Undeclared" by the department.

Transfer Students

Students are initially identified as "pre-majors", and will be admitted to the Bioengine-ering: Premedical major based on academic performance in ten prerequisite courses. It is expected that students will have completed or have in progress all ten prerequisite courses when applying to UCSD. Students are required to achieve a GPA of 3.0 or better in the ten prerequisite premajor courses (Mathematics 20A-B-C; Physics 2A-B; Chemistry 6A; MAE 9 or 10, and three other courses required by the major) by the end of the third quarter of study at UCSD. **Note**: *Two of the prerequisite courses must be taken at UCSD, one of which must be an upper-division course.* Students need to contact the Student Affairs Office at the end of their third quarter at UCSD to check on their status and complete an Undergraduate Change of Major Request form.

ADMISSION TO BIOENGINEERING: BIOINFORMATICS

As the number of pre-majors and majors will be limited as described in the catalog section on Bioinformatics, student demand may exceed program capacity. Therefore, admission to the major is not guaranteed and will be based on academic excellence, as described below. Since Bioinformatics is an interdisciplinary major, a Steering Committee involving faculty from the participating departments will select among the best candidates applying and recommended through each department, while insuring active participation of the departments and division offering the major.

Freshman Students

Bioengineering: Bioinformatics has been recently developed, and there is a multi-step process into this major for students entering UCSD as freshmen. First, high school students should apply to UCSD for direct admission into the Bioengineering, Bioengineering: Biotechnology, or Pre-Bioengineering: Premedical major. Those admitted should then complete the freshman courses, prescribed in the preceding Table for the Bioengineering: Bioinformatics major. After completing BILD 1, Chem. 6A, Math. 20B, and Math. 20C during the freshman year, such students can apply to Pre-Bioengineering: Bioinformatics. Admission will be based primarily on the GPA in the four preceding courses, but also on a written statement, completion of the other listed requirements, and overall academic excellence. Students approved for Pre-Bioengineering: Bioinformatics should then continue with the sophomore courses, prescribed in the preceding Table, including CSE 11 and 12 which serve as two additional screening courses. By the end of the sophomore year, these students can then apply to major in Bioengineering: Bioinformatics. Admission to the Bioengineering: Bioinformatics major will be based on the GPA in all six screening courses. The final decision on admission to the pre-major and major will be made by the Bioinformatics Steering Committee, in consultation with the departments. Those students who are not selected for the Bioengineering: Bioinformatics major, will be eligible to remain in the Department of Bioengineering in the status in which they were originally admitted.

Continuing Students

Students who have not declared the Pre-Bioengineering: Bioinformatics major, but who have completed the screening courses for the Bioengineering: Bioinformatics major, may apply for entry to the program after six quarters (the end of sophomore year). Students will be admitted on a space-available basis, after pre-majors have been screened for admission to the major.

Transfer Students

As Bioengineering: Bioinformatics has been recently developed, there is a multi-step process into this major for transfer students. First, such students should complete at their community colleges as many of the following courses as possible, with a strong GPA that is competitive with that of UCSD students applying for entry into this major. The required courses include a year of calculus (equivalent to Math. 20A, 20B, and 20C), two quarters of biology (equivalent to BILD 1 and 2), a year of general chemistry with laboratory (equivalent to Chem. 6A, 6B, 6C, and 6BL), and the highest level programming courses (equivalent to CSE 11 and 12). Next, such students should apply to UCSD for direct admission into the Bioengineering, Bioengineering: Bio-technology, or Pre-Bioengineering: Premedi-cal major. After completing the necessary screening requirements equivalent to those that apply for students entering UCSD as freshmen, such students can apply to Pre-Bioengineering: Bioinformatics and subsequently apply to major in Bioengineering: Bioinformatics. Admission will be based primarily on the GPA in the required screening courses, but also on a written statement, completion of the other listed requirements and overall academic excellence. The final decision on admission to the pre-major and major will be made by the Bioinformatics Steering Committee, in consultation with the departments. Those who are not selected for the Bioengineering: Bioinformatics major, will be eligible to remain in the Department of Bioengineering in the status in which they were originally admitted.

ACADEMIC ADVISING

Upon admission to the major, students are encouraged to seek advice from departmental staff in the Bioengineering Student Affairs Office, Room 141, Powell-Focht Bioengineering Hall, to plan a program of study. Students are expected to chart their progress within their major. The program plan may be revised in subsequent years, but revisions involving curricular requirements require approval of the undergraduate adviser and the Undergraduate Studies Committee. As the department may make a small number of course and/or curricular changes every year, it is imperative that students consult the undergraduate adviser on an annual basis.

To enroll in any courses required for a bioengineering major, a student must have satisfied prerequisite courses with a C– or better. (The department does not consider D or F grades as adequate preparation for subsequent material.) Furthermore, the majority of bioengineering courses have enrollment restrictions and are open only to students who have been admitted to a bioengineering pre-major or major. Where these restrictions apply, the registrar will not enroll other students except by department approval. The department expects students to adhere to these policies and enroll in courses accordingly. Students are advised that they may be dropped from course rosters if prerequisites and/or performance standards have not been met.

Bioengineering courses are typically offered only once a year and therefore should be taken in the recommended sequence. If courses are taken out of sequence, it may not always be possible to enroll in courses as desired or needed for timely graduation. If this occurs, students should seek immediate departmental advice.

Programmatic advice may be obtained from the Student Affairs Office. In addition, technical advice may be obtained from a specific bioengineering faculty adviser assigned to each student upon admission to the major.

PROGRAM ALTERATIONS, EXCEPTIONS TO REQUIREMENTS, AND SPECIAL PROGRAMS

Exceptions to any program or course requirements are possible if approved by the Undergraduate Studies Committee *before* the courses in question are taken. Petitions may be obtained from the Bioengineering Student Affairs Office.

Independent Study for Undergraduates

Under the guidance of a bioengineering faculty member, lower- and upper-division level bioengineering students have opportunities to participate in independent study and research.

Upper-division bioengineering students may take Bioengineering 199, Independent Study for Undergraduates. Lower-division bioengineering students may enroll in Bioengineering 99 which is similar to Bioengineering 199, except that less background in the curriculum is needed. These courses are taken as electives on a P/NP basis. Under certain conditions, however, a Bioengineering 199 course may be used to satisfy upper-division technical elective course requirements for the major. Students interested in this alternative must identify a faculty member with whom they wish to work and propose a two-quarter research or study topic for *Bioengineering* (the other technical elective must be an engineering course) and *Bioengineering: Biotechnology* majors, and a one-quarter research topic for *Bioengineering: Premedical* majors. After obtaining the faculty adviser's concurrence on the topic and scope of the study, the student must submit a *Special Studies* course form (each quarter) and a *Bioengineering 199 as Technical Elective Contract* to the Undergraduate Studies Committee. These forms must be completed, approved, and processed prior to the beginning of the quarter in which the course is to be taken.

Teaching

Students interested in participating in the instructional activities of the department may take Bioengineering 195, Undergraduate Teaching as an elective on a P/NP basis. Under certain conditions, it may be used to satisfy upper-division technical elective course requirements for the *Bioengineering: Premedical* major. Policy in this regard may be obtained from the Student Affairs Office.

Integrated Bachelor's/ Master's Degree Program

An integrated program leading to a bachelor of science and a master of science degree in bioengineering is offered to undergraduate students who are enrolled in any of the major programs offered by the Department of Bioengineering. Students interested in obtaining the M.S. degree within one year following completion of the B.S. degree may apply to the department for admission to the program during the fourth quarter *prior* to the receipt of the B.S. degree. The program is open only to UCSD undergraduates.

To be eligible, students must have completed the first two quarters of their junior year in residence at UCSD and have an upper-division GPA of 3.5 or better and a 3.0 overall UC GPA. Twelve

units of bioengineering graduate level courses must be completed during the student's senior undergraduate year, *in addition* to the requirements for the bachelor's degree; these twelve units will count toward the requirements for the master's degree only and must be taken for a letter grade. It is the responsibility of the prospective B.S./M.S. student to select a bioengineering faculty member who is willing to serve as the student's adviser. The student will also arrange (with their faculty adviser's approval) a schedule of courses for the senior year that will fulfill the requirements for the B.S. degree while also serving the program planned for the M.S. degree. Students are expected to meet the requirements for the M.S. degree in one year (three consecutive academic quarters) from the date of the receipt of the B.S. degree.

Industrial Internship Program and Graduate Industrial Training Program

The Department of Bioengineering offers two industrial programs: the **Industrial Internship Program** for undergraduates and the **Graduate Industrial Training Program** for graduate students. Both industrial programs are designed to complement the department's academic curriculum with practical industry experience. Students interested in these programs should contact the Bioengineering Industrial Internship Office (125 Powell-Focht Bioengineering Hall) well in advance of the quarter in which they would like to start their internship.

The Industrial Internship Program is available to undergraduate students who have completed all lower-division course requirements. Academic credit under Bioengineering 196, Bioengineering Industrial Internship can be earned by spending ten weeks or more as interns in an industrial setting. The intern may be involved in a range of activities including design, analysis, manufacturing, testing, regulatory affairs, etc., under the direction of a mentor in the workplace. At the completion of the internship experience, students are required to submit a brief report to the mentor and faculty adviser describing their activities.

The Graduate Industrial Training Program is designed for students in the Master of Engineering Degree Program. This program serves to significantly enhance the professional development of M.Eng. students in preparation for leadership in the bioengineering industry. Students will complete an independent industrial bioengineering project in the setting of a company under the direction of an industrial and faculty adviser.

The Graduate Program

Admission to the M.Eng. M.S., and Ph.D., as well as to the Ph.D. with a specialization in bioinformatics programs, is in accordance with the general requirements of the graduate division. Applicants are required to have completed a B.S. and/or M.S. degree by time of admission in a branch of engineering, natural sciences, mathematics, or quantitative life sciences. M.S. and Ph.D. applicants must have a GPA of 3.4 or better in technical courses. M.Eng. applicants should have competitive grades (greater than a 3.0 GPA). All applicants must submit GRE General Test scores, as well as three letters of recommendation from individuals who can attest to the academic or professional competence and to the depth of their interest in pursuing graduate study. Attention will be paid to the background and statement of purpose to ensure that they are consistent with the goals of the program. For example, whereas undergraduate research experience and the intention to pursue a research career or advanced studies are qualifications and interests typically well-suited to the M.S. program, industrial experience and the intention to pursue a professional career are better suited to the M.Eng. program.

A minimum score of 550 (paperbased) or 213 (computer based) on the Test of English as a Foreign Language (TOEFL) is required of all international applicants whose native language is not English and whose undergraduate education was conducted in a language other than English. Students who score below 600 on the TOEFL examination are strongly encouraged to enroll in an English as a Second Language program before beginning graduate work. (UCSD Extension offers an English language program during the summer as well as the academic year.) Admission to the M.S. or Ph.D. is designated when the applicants are judged to be appropriately qualified to pursue the degree requested at the time of application. Applicants are considered for admission for the fall quarter only.

A new graduate student who does not meet the prerequisites of required courses in the M.Eng., M.S., or Ph.D. curricula may have to take some basic courses to make up the deficiency. Thus, a student deficient in mathematics and mechanics may have to take Math. 110, CENG 103B or Bioengineering 103B, Bioengineering 110, 122A-B in the first year and Bioengineering 250A-B, 253 in the second year. A student deficient in biology and chemistry may have to take Chemistry 131 or Bioengineering 130 and BIPN 100, 102 in the first year and Bioengineering 230A-B-C in the second year.

Non-matriculated students are welcome to seek enrollment in bioengineering courses via UCSD Extension's concurrent registration program, but such enrollment in a bioengineering graduate course must be approved by the instructor.

Master of Science Degree Programs

The Master of Science **(M.S.) program** is intended to extend and broaden an undergraduate background and equip the graduates with fundamental knowledge in bioengineering. It is intended for those students wishing to gain experience in academic research, especially those considering continuing graduate studies at the doctoral level. The M.S. degree may be terminal or may be obtained on the way to the Ph.D. or by completing the course requirements of the M.S. degree and by passing the Ph.D. departmental examination.

An individualized program is agreed upon by the student and a faculty adviser. The plan of study must involve both course work and research, culminating in the preparation of a thesis.

A total of **forty-eight units** of credit is required:

- **Thirty-six units in course work**
  Nine courses, of which six are core courses, described below, and three are elective courses which can be drawn from Bioengineering course offerings, other engineering/science course offerings, and School of Medicine courses. *The faculty adviser must approve the three elective courses.*
- **Twelve units in research**
  Bioengineering Research (BENG 299) under the direction of the chosen faculty research adviser.

A thesis based on the research is written and subsequently reviewed by the thesis adviser and two other faculty members appointed by the dean

of Graduate Studies. The oral defense of the thesis constitutes the departmental master's exam.

REQUIRED CORE COURSES FOR M.S. DEGREE PROGRAM

Integrative Bioengineering

- BENG 250A. Biomechanics
- BENG 253. Biomedical Transport Phenomena
- A third required course chosen from a list of approved courses that satisfy the Integrative Bioengineering requirement i.e., Advanced Biomechanics 250B, Biomedical Imaging BENG 280B, Bioinformatics III—Genomic Analysis BENG 203, or other core Bioengineering graduate courses that satisfy the Integrative Bioengineering requirement as approved by the Graduate Studies Committee. A list of applicable approved courses is available from the Department of Bioengineering Student Affairs Office.

Life Science

- BENG 230A. Biochemistry
- BENG 230B. Cell and Molecular Biology
- BENG 230C. Cardiovascular Physiology

Restrictions to core course work requirements are as follows:

1. Units obtained in Bioengineering 281, or 299 or 501 may not be applied toward the course work requirement.
2. No more than a total of eight units of Bioengineering 296 and 298 may be applied toward the course work requirement.
3. No more than twelve units of upper-division 100-level Bioengineering courses may be applied toward the course work requirement.

Students must maintain at least a B average in the courses taken to fulfill the degree requirements.

MASTER'S TIME LIMIT POLICY

Full-time M.S. students are permitted seven quarters in which to complete all requirements. While there are no written time limits for part-time students, the department has the right to set individual deadlines if necessary.

A strong effort is made to schedule M.S.–level course offerings so that students may obtain their M.S. degree in one year of full-time study or two years of part-time study *(see regulations on part-time study under "Graduate Studies")*. Entering students who do not meet the prerequisites of these core courses may have to take some basic courses to make up the deficiency.

A candidate admitted for the M.S. degree who wishes to transfer to the Ph.D. program must consult the Student Affairs Office for the transfer before completion of the M.S. program.

CHANGE OF DEGREE AIM

Upon completion of the requirements for the M.S. degree, students are not automatically eligible for admission to the Ph.D. program.

M.S. candidates who wish to pursue a doctorate must submit an application for a change in status to the Graduate Studies Committee. The application must be approved and signed by a bioengineering faculty member who expects to serve as the student's Ph.D. adviser. Applications will be reviewed by an ad hoc faculty committee. If the committee recommends that the student has good potential for success in the doctoral program, the student will be given the opportunity to take an oral examination equivalent to the Ph.D. Departmental Qualifying Examination. At the time of that exam, an assessment will be made on admission to the Ph.D. program.

A change of status from a master's program to the doctoral program requires that the student meet the minimal grade-point average required by the department of doctoral candidates.

Master of Engineering Degree Program

The department offers a Master of Engineering **(M.Eng.) degree**. The purpose of this degree is to prepare design and project engineers for careers in the biomedical and biotechnology industries within the framework of the graduate program of the Department of Bioengineering. It is a terminal professional degree in engineering which includes a recognition of the importance of breadth in technical knowledge, sufficient electives to address job-specific interests and professional skills such as economics, management, and business. It is intended for students who are primarily interested in engineering design, development, manufacturing, and management within an industrial setting.

The M.Eng. program is a flexible, course-intensive terminal professional degree, designed to be completed in one academic year of full-time study. It does not require a research project, a thesis, or a comprehensive exam. However, students do have the option in enrolling for technical credit in BENG 295 *Bioengineering Design Project and Industrial Training* under the direction of a faculty adviser. This is done by participating in the Graduate Industrial Training Program which allows students to work in an industrial setting on bioengineering projects in order to gain practical experience. *(See section on **Industrial Internship Program** and **Graduate Industrial Training Program**.)* Students who may be interested in continuing to the Ph.D. program should apply to the M.S. program and not the terminal M.Eng. degree.

Students must select **six** courses from approved core areas, **three** additional approved technical elective courses from any graduate engineering program, and **three** general elective courses which may be drawn from the Bioengineering core areas, engineering technical electives or other non-technical courses. Such core courses and technical and general electives are described below. In selecting breadth courses, students must be mindful of the prerequisite requirements for some of the courses in the lists. The lists below are based on the current graduate course offerings of the bioengineering and other engineering departments. The Graduate Studies Committee will review the M.Eng. course lists annually and update them as course offerings change. Students must maintain at least a B average in the courses taken to fulfill the degree requirements.

Required Core Courses for M.Eng. Program (Six Required)

- Biomechanics and Transport Phenomena—BENG 250A-B, 253
- Tissue Engineering—BENG 241A-B-C
- Life Science—BENG 230A-B-C
- Other approved core graduate courses taught by Bioengineering faculty that satisfy the depth requirement of the M. Eng. degree as approved by the Graduate Studies Committee. A list of applicable approved courses is available from the Department of Bioengineering Student Affairs Office.

Examples of Technical Electives for M.Eng. (Three Required)

BENG 295. Bioengineering Design Project (two-quarters, four units each)
MAE 231A-B-C. Solid Mechanics
MAE 210A-B-C. Fluid Mechanics

MAE 221A-B-C. Heat and Mass Transfer
MAE 229A. Mechanical Properties
CSE 202. Algorithm Design and Analysis
CSE 210. Principles of Software Engineering
CSE 250A. Artificial Intelligence
ECE 239. Nanometer-Scale Probes and Devices
ECE 251AN, BN. Digital Image Processing and Analysis

Examples of General Electives for M.Eng. (Three Required)

BENG 161A-B-C. Biochemical Engineering
BENG 186A-B-C. Principles of Biomaterials, Bioinstrumentation and Bioengineering Design.
IR/PS Management: IRGN 438, 439, 442, 444, 445, 420, 434, IRCO 420, 421
IR/PS International Issues: IRCO 401, IRGN 407, 411, 413, 418
MAE 133. Finite Element Method
Phys. 206. Biophysics

Sample M.Eng. Program of Study

FALL	WINTER	SPRING
BENG 230A	BENG 230B	BENG 230C
Tech Elec	BENG 250A	BENG 250C
Gen Elec	BENG 253	Tech Elec
Gen Elec	Tech Elec	Gen Elec

Doctoral Degree Program

The Bioengineering Ph.D. Program is intended to prepare students for a variety of careers in research and teaching. Therefore, depending on the student's background and ability, research is initiated as soon as possible. Bioengineering students have specific course requirements and must maintain a minimum grade-point average of 3.4 in these courses. Students, in consultation with their advisers, develop course programs that will prepare them for the Departmental Qualifying Examination and for their dissertation research. These programs of study and research must be planned to meet the time limits established to advance to candidacy and to complete the requirements for the degree. Doctoral students who have passed the Departmental Qualifying Examination may take any course for an S/U grade with the exception of courses required by the Departmental or Senate Qualifying Examination Committee. It is recommended that all bioengineering graduate students take a minimum of two courses (other than research) per academic year after passing the Departmental Qualifying Examination. Details can be obtained from the Student Affairs Office.

Doctoral Examinations

A bioengineering Ph.D. student is required to pass three examinations. The first is a Departmental Qualifying Examination which must be taken immediately following the candidate's first academic year of enrollment. The exam is designed to ensure that all successful candidates possess a firm command of the engineering and life science subjects that form the foundations of bioengineering research and their integration at a level appropriate for the doctorate. It is administered by a committee designated by the department, consisting of departmental faculty members and, in some cases, one other faculty member from a related academic department (e.g., MAE, ECE, Medicine). The scope of the oral examination includes the three broad areas that form the core first-year Ph.D. curriculum, namely engineering foundations, life science, and integrative bioengineering. The purpose of the exam is not merely to recapitulate the content of first-year courses, but rather to establish that students are able to synthesize this knowledge and apply it to solve problems in contemporary bioengineering research.

1. **Engineering Foundations**

   Defined by the content of three graduate engineering courses drawn from the following:

   BENG 202/CSE 257A. Bioinformatics II: Sequence and Structure Analysis
   BENG 203. Bioinformatics III:Genomic Analysis
   BENG 209/MAE 209. Continuum Mechanics Applied to Medicine/Biology
   BENG 275. Computational Biomechanics
   BENG 280A. Principles of Biomedical Imaging
   CSE 202. Algorithm Design and Analysis
   ECE 222A. Applied Electromagnetic Theory
   ECE 238A. Thermodynamics of Solids
   ECE 247A/BENG 247A. Advanced Biophotonics
   ECE 247B/BENG 247B. Bioelectronics
   ECE 247C/BENG 247C. Bionanotechnology
   ECE 251AN. Digital Signal Processing
   ECE 270A-B-C. Neurocomputing
   MAE 210A. Fluid Mechanics (best suited to students with some undergraduate background in mechanics or mechanical engineering)
   MAE 221A. Heat and Mass Transfer
   MAE 223. Computational Fluid Dynamics
   MAE 231A. Foundations of Solid Mechanics (best suited to students with some undergraduate background in mechanics or mechanical engineering)
   MAE 233A. Fracture Mechanics
   MAE 252. Chemical Reaction Engineering
   MAE 280A. Linear Systems Theory
   MAE 281A. Nonlinear Systems
   MAE 290A. Numerical Methods in Science and Engineering
   MATS 201B. Solid State Diffusion and Reaction Kinetics

   Other topics may be approved by the Graduate Studies Committee

2. **Integrative Bioengineering**

   Defined by the content of the following three bioengineering courses:

   - BENG 250A. Biomechanics
   - BENG 253. Biomedical Transport Phenomena
   - A third required course chosen from a list of approved courses that satisfy the Integrative Bioengineering requirement i.e., Advanced Biomechanics BENG 250B, Biomedical Imaging BENG 280B, Systems Biology and Bioengineering: Building-In-Silico models BENG 213, or other core Bioengineering graduate courses that satisfy the Integrative Bioengineering requirement as approved by the Graduate Studies Committee. A list of applicable approved courses is available from the Department of Bioengineering Student Affairs Office.

3. **Life Science**

   The life science subject area consists of the following topics: biochemistry, cell and molecular biology, organ physiology, and tissue engineering. These subject areas are defined by the contents of the following four courses:

   - BENG 230B. Cell and Molecular Biology
   - BENG 230C. Cardiovascular Physiology or BENG 230D. Respiratory and Renal Physiology
   - BENG 241A. Foundations of Tissue Engineering
   - BENG 230A. Biochemistry or CHEM 211. Metabolic Biochemistry

In addition to the above mentioned breadth requirements, students must complete the following courses in their second and subsequent years of study:

- At least two courses from an approved list that includes the continuation of Bioengineering Foundations course sequences, BENG 230D, Pharm. 201, Math. 283, and other bioengineering graduate course sequences.
- One quarter of BENG 501, Teaching Experience
- BENG 281, Seminar in Bioengineering (F,W,S)

Courses comprising subject areas as well as subsequent requirements, and composition of the examination committee must be approved by the Graduate Studies Committee. Students are advised to seek such approval well in advance of their expected examination date, preferably while planning graduate studies.

Teaching Experience is required of all bioengineering Ph.D. students prior to taking the Senate Qualifying Exam described below. Teaching experience is defined as service as a graduate student instructor in a course designated by the department. The total teaching requirement for new Ph.D. students is four quarters at 25 percent effort (ten hours per week). At least one quarter of teaching experience is required during the first year (prior to the departmental qualifying examination) and at least one quarter in the second year. Teaching experience can be fulfilled as a requirement for student support or taken as a course for academic credit (Bioengineering 501). Students must contact the Student Affairs Office to plan for completion of this requirement.

The **Senate Qualifying Examination** is the second examination required of bioengineering Ph.D. students. In preparation for this examination, students must have completed the Departmental Qualifying Examination and the departmental teaching experience requirement, obtained a faculty research adviser, and identified a topic for their dissertation research and made initial progress. At the time of application for advancement to candidacy, a doctoral committee responsible for the remainder of the student's graduate program is appointed by the Graduate Council. The committee conducts the Senate Qualifying Examination, during which students must demonstrate the ability to engage in thesis research. This involves the presentation and defense of a plan for the thesis research project. Upon successful completion of this examination, students are advanced to candidacy and are awarded the Candidate in Philosophy degree *(see "Graduate Studies" section in this catalog)*.

The **Dissertation Defense** is the final Ph.D. examination. Upon completion of the dissertation research project, the student writes a dissertation that must be successfully defended in a public presentation and oral examination conducted by the doctoral committee. A complete copy of the student's dissertation must be submitted to each member of the doctoral committee approximately four weeks before the defense. It is understood that this copy of the dissertation given to committee members will not be the final copy, and that the committee members may suggest changes in the text at the time of the defense. This examination must be conducted after at least three quarters of the date of advancement to doctoral candidacy. Acceptance of the dissertation by the Office of Graduate Studies and Research and the university librarian represents the final step in completion of all requirements for the Ph.D.

There is no formal foreign language requirement for doctoral candidates. Students are expected to master whatever language is needed for the pursuit of their own research.

Ph.D. Time Limit Policy

Pre-candidacy status is limited to four years. Doctoral students are eligible for university support for six years. The defense and submission of the doctoral dissertation must be within seven years.

Evaluations

In the spring of each year, the faculty evaluate each doctoral student's overall performance in course work, research, and prospects for financial support for future years. A written assessment is given to the student after the evaluation. If a student's work is found to be inadequate, the faculty may determine that the student cannot continue in the graduate program.

COURSES

Note: The department will endeavor to offer the courses as outlined below; however, unforeseen circumstances sometimes mandate a change of scheduled offerings. Students are strongly advised to check with the department's Student Affairs Office. This is of particular importance in planning schedules for graduation requirements. The following schedule is tentative for the academic year 2004–2005 only.

It should not be assumed that the same schedule will continue after this academic year. It is the student's responsibility to contact the Student Affairs Office to determine the specific quarter that courses will be offered.

Prerequisites are enforced when adding courses. Students who have satisfied prerequisites at another institution or by AP credit need to be pre-authorized to register in these courses. Please contact the Student Affairs Office before your scheduled registration time to be pre-authorized.

LOWER-DIVISION

1. Introduction to Bioengineering (1)
An introduction to the central topics of bioengineering in a seminar format. The principles of problem definition, team design, engineering inventiveness, information access, communication, ethics, and social responsibility will be emphasized. P/NP grading only. *Prerequisite: none.* (W).

87. Freshman Seminar (1)
The Freshman Seminar Program is designed to provide new students with the opportunity to explore an intellectual topic with a faculty member in a small seminar setting. Freshman seminars are offered in all campus departments and undergraduate colleges, and topics vary from quarter to quarter. Enrollment is limited to fifteen to twenty students, with preference given to entering freshmen. (F,W,S)

90. Undergraduate Seminar (1)
Selected topics of interest to the faculty will be used to introduce students to bioengineering science and design concepts. (Not open to upper-division bioengineering students.) (F,W,S)

97. Internship/Field Studies (1-4)
An enrichment program available to a limited number of lower-division undergraduate students, which provides work experience with industry, government offices, and hospitals. The internship is coordinated through UCSD's Academic Internship Program under the supervision of a faculty member and an industrial, government, or hospital employee. Prerequisites: lower-division standing, completion of thirty units of UCSD undergraduate study, a minimum UCSD GPA of 3.0, and a completed and approved "Special Studies" form, "UCSD Application for Enrollment Special Studies Courses 97, 98, 99." (F,W,S)

98. Directed Group Study (1-4)
Directed group study on a topic or in a field not included in the regular department curriculum. (P/NP grades only.) Prerequisites: lower-division standing, completion of thirty units of undergraduate study at UCSD with a UCSD GPA of at least 3.0 and consent of a bioengineering faculty member; completed and approved Special Studies form.

99. Independent Study for Undergraduates (4)
Independent reading or research by arrangement with a bioengineering faculty member. (P/NP grades only.) Prerequisites: lower-division standing, completion of thirty units of undergraduate study at UCSD

with a UCSD GPA of at least 3.0 and consent of a bioengineering faculty member; completed and approved Special Studies form.

UPPER-DIVISION

100. Introduction to Bioengineering Design (4)
A general introduction to bioengineering design, including examples of engineering analysis and design applied to representative topics in biomechanics, bioinstrumentation, biomaterials, biotechnology, and related areas. A review of technological needs, design methodology, testing procedures, statistical analysis, governmental regulation, evaluation of costs and benefits, quality of life, and ethical issues. *Prerequisites: BENG 1; grade of C– or better in Math. 21C or Math. 20C and Math. 21D or Math. 20D, and Physics 2C; majors only.* (S)

101. Foundations of Biomedical Imaging (4)
An introduction to the principles and applications of biomedical imaging, with emphasis on the acquisition, processing, display of imagery, and design of imaging systems. Filtering, convolution, and Fourier methods. Microscopy, radiography, computed tomography, magnetic resonance, ultrasound, and nuclear imaging. *Prerequisites: Grade of C- or better in BENG 100; majors only or consent of department.* (F)

103B. Bioengineering Mass Transfer (4)
Mass transfer in solids, liquids, and gases with application to biological systems. Free and facilitated diffusion. Convective mass transfer. Diffusion-reaction phenomena. Active transport. Biological mass transfer coefficients. Steady and unsteady state. Flux-force relationships. (Students may not receive credit for both CENG 101C and BENG 103B.) *Prerequisites: grade of C– or better in BENG 112A; majors only.* (S)

106B. Bioengineering Dynamics (4)
Kinematics and kinetics of particles and rigid bodies. Muscle and joint loads. Musculoskeletal dynamics, locomotion, and clinical applications. Bodies in contact: friction, momentum, and impulse; impact and injury. Work, power, and energy relationships; conservation laws of dynamics. Bioengineering design problems, problem formulation, and problem solutions. (Students may receive credit for one of the following: MAE 130B, SE 101B, or BENG 106B.) *Prerequisites: grade of C– or better in Math. 21D or Math 20D and MAE 130A/SE 101A; majors only.* (W)

110. Continuum Mechanics (4)
An introduction to continuum mechanics of both living and non living bodies. The laws of motion and free-body diagrams. Stresses. Deformation. Compatibility conditions. Constitutive equations. Properties of common fluids and solids. Derivation of field equations and boundary conditions. Applications to bioengineering design. *Prerequisites: grades of C– or better in Physics 2A, 2B, 2C; majors only.* (F)

112A. Biomechanics (4)
Introduction to physiological systems, with emphasis on structure and function of major tissues and organs. Application of mechanics to understand the behavior of these tissues and organs at gross and microscopic levels. Bioelastic solids. Rigid body biomechanics. Biofluids. Bioengineering and medical design. *Prerequisites: grade of C– or better in BENG 110; majors only.* (W)

112B. Biomechanics (4)
Biomechanics of living tissues with emphasis on continuum analysis of problems in biofluid and cell mechanics. Engineering design and problem solving in the biomechanics of mammalian tissues, especially those of the cardiovascular system. *Prerequisites: grade of C– or better in BENG 112A; majors only.* (S)

122A. Biosystems and Control (4)
Systems and control theory applied to bioengineering. Modeling, linearization, transfer functions, Laplace transforms, closed-loop systems, design and simulation of controllers. Dynamic behavior and controls of first and second order processes. PID controllers. Stability. Bode design. Features of biological controls systems. A simulation term project using MATLAB and an oral presentation are required. *Prerequisites: grade of C– or better in MAE 140; majors only or consent of department.* (W)

122B. Biomedical Electronics (4)
Analog and digital circuits in bioinstrumentation. Biomedical signals in continuous and discrete systems. Sampling and digital signal processing. MRI. CT. Ultrasound. Bioelectromagnetics. Electrokinetics. *Prerequisites: grade of C– or better in BENG 122A and BENG 186B; majors only or permission of instructor.* (S)

123. Systems Biology and Bioengineering (4)
Systems biology and bioengineering is comprised of (1) enumeration of biological components participating in a biological process, (2) reconstruction of interactions to form a network, (3) mathematical representation for analysis, interpretation, and prediction, (4) model validation and use in prospective design. Prerequisites: grade of C– or better in BIBC 100; majors only. (W)

125. Modeling and Computation in Bioengineering (4)
Computational modeling of molecular bioengineering phenomena: excitable cells, regulatory networks, and transport. Application of ordinary, stochastic, and partial differential equations. Introduction to data analysis techniques: power spectra, wavelets, and nonlinear time series analysis. Prerequisites: grade of C– or better in BENG 122A or BENG 123; majors only or consent of instructor. (S)

130. Molecular Physical Chemistry (4)
An introduction to physical principles that govern biological matter and processes.Thermodynamic principles and their molecular origin, structural basis of life and physical and conceptual models to illustrate life phenomena. (Students may receive credit for one of the following: Chem. 126, Chem. 127, Chem. 131, or BENG 130.) *Prerequisites: grade of C– or better in Chem 6B, Math. 20A, 20B, Physics 2A, 2B, 2C. (Physics 2C may be taken concurrently.); majors only.* (W)

140A. Bioengineering Physiology (4)
Introductory mammalian physiology for bioengineering students, with emphasis on control mechanisms and engineering principles. Basic cell functions; biological control systems; muscle; neural; endocrine, and circulatory systems. Not intended for premedical bioengineering students. (Students may not receive credit for both BIPN 100 and BENG 140A.) *Prerequisites: grade of C– or better in Chem. 6A, 6B, Physics 2A, 2B, 2C, BILD 1; majors only.* (W).

140B. Bioengineering Physiology (4)
Introductory mammalian physiology for bioengineering students, with emphasis on control mechanisms and engineering principles. Digestive, respiratory, renal, and reproductive systems; regulation of metabolism, and defense mechanisms. (Students may not receive credit for both BIPN 102 and BENG 140B.) *Prerequisite: grade of C– or better in BENG 140A; majors only*. (S).

161A. Bioreactor Engineering (4)
Introduction to the principles and practices of biochemical engineering. Important engineering, biochemical and physiological considerations in the design of bioreactor processes: enzyme kinetics, mass transfer limitations, microbial growth, and product formation kinetics. Fermentation reactor selection, design, scale-up, and control. *Prerequisites: grade of C– or better in Chem 114B or BIBC 102 (may be taken concurrently), BENG 122A and admission to the major.* (F)

161B. Biochemical Engineering (4)
Commercial production of biochemical commodity products. Application of genetic control systems and mutant populations. Recombinant DNA and eucaryotic proteins in E. coli and other host organisms. Product recovery operations, including the design of bioseparation processes of filtration, adsorption, chromatography, and crystallization. Bioprocess economics. Human recombinant erythropoietin as an example, from genomic cloning to CHO cell expression, to bioreactor manufacturing and purification of medical products for clinical application. *Prerequisite: grade of C– or better in BENG 161A; majors only.* (W)

161C. Metabolic Engineering (4)
Engineering systems analysis of metabolic and regulatory processes. Use of high-throughput data for network reconstruction. Formulation of the stoichiometric matrix and its uses to determine steady state flux distributions. Kinetics of individual enzymatic reactions. Computer simulations of metabolic networks, systemic sensitivity coefficients, bifurcations to study dynamic network functions. Temporal decomposition of metabolic processes into multiple time scales and the physiologic roles of metabolic events in each scale. *Prerequisite: grade of C– or better in BENG 161B; majors only.* (S)

162. Biotechnology Laboratory (4)
Laboratory practices and design principles for biotechnology. Culture of microorganisms and mammalian cells, recombinant DNA bioreactor design and operation. Design and implementation of biosensors. A team design-based term project and oral presentation required. *Prerequisites: admission to the major; MAE 170, BENG 166A, BENG 161B (must be taken concurrently)*. (W)

164. Bioengineering of Biochemical Techniques (1)
Quantitative bioengineering analysis and design of biochemical processes and experiments on biological molecules. Centrifugation, electrophoresis, chromatography. Radioactive tracers. Enzyme activity. Immunoassay. *Prerequisites: admission to the major; grade of C– or better in BENG 161B and BIBC 103 (may be taken concurrently)*. (S)

166A. Cell and Tissue Engineering (4)
Engineering analysis of physico-chemical rate processes that affect, limit, and govern the function of cells and tissues. Cell migration, mitosis, apoptosis, and differentiation. Dynamic and structural interactions between mesenchyme and parenchyme. The role of the tissue microenvironment including cell-cell interactions, extracellular matrix, and growth factor communication. The design of functional tissue substitutes including cell and material sourcing, scale-up and manufacturability, efficacy and safety, regulatory, and ethical topics. Clinical Applications. *Prerequisite: admission*

to the major or consent of department; senior standing and (BENG 103B OR BENG 112B). (F)

168. Biomolecular Engineering (4)
Basic molecular biology; recombinant DNA technologies; design and manufacture of recombinant proteins and genetically engineered cells; architecture and mechanism of molecular nano-machineries that perform gene regulation, energy conversion, enzymatic catalysis, and active transport. Prerequisites: BILD 1 and BENG 100; majors only or consent of instructor. (S)

172. Bioengineering Laboratory (4)
A laboratory course which demonstrates basic concepts of bioengineering design through experimental procedures involving humans and animals. Statistical principles of experimental design. Study of possible errors. Experiments include nerve action, electrocardiography, mechanics of muscle, membranes, and noninvasive diagnostics in humans. *Prerequisites: grade of C– or better in MAE 170 and junior or senior standing in the major.* (S)

181/BIMM 181/CSE 181. Molecular Sequence Analysis (4)
(Cross-listed as BIMM 181 and CSE 181.) This course covers the analysis of nucleic acid and protein sequences, with an emphasis on the application of algorithms to biological problems. Topics include sequence alignments, database searching, comparative genomics, and phylogenetic and clustering analyses. Pairwise alignment, multiple alignment, DNA sequencing, scoring functions, fast database search, comparative genomics, clustering, phylogenetic trees, gene finding/DNA statistics. *Prerequisites: CSE 100 or Math. 176, CSE 101 or Math. 188, BIMM 100 or Chem. 114C; Bioinformatics majors only.* (S)

182/BIMM 182/CSE 182/CHEM182. Biological Databases (4)
(Cross-listed as BIMM 182, CSE 182, and Chem. 182.) This course provides an introduction to the features of biological data, how those data are organized efficiently in databases, and how existing data resources can be utilized to solve a variety of biological problems. Object oriented databases, data modeling and description. Survey of current biological database with respect to above, implementation of database focused on a biological topic. *Prerequisite: CSE 100 or Math. 176; Bioinformatics majors only.* (F)

183. Applied Genomic Technologies (4)
Principles and technologies for using genomic information for biomedical applications. Technologies will be introduced progressively, from DNA to RNA to protein to whole cell systems. The integration of biology, chemistry, engineering, and computation will be stressed. Topics include: Technology for the Genome, DNA Chips, RNA Technologies, Proteomic Technologies, Physiomic and Phenomic Technologies, Analysis of Cell Function. *Prerequisite: grade of C– or better in BIMM 100 or Chem 114C; BICD 110; Bioinformatics majors only.* (F)

184/BIMM 184/CSE 184. Computational Molecular Biology (4)
(Cross-listed as BIMM 184 and CSE 184.) This advanced course covers the application of machine learning and modeling techniques to biological systems. Topics include gene structure, recognition of DNA and protein sequence patterns, classification, and protein structure prediction. Pattern discovery, hidden Markov models/support vector machines/neural network/profiles, protein structure prediction, functional characterization of proteins, functional genomics/proteomics, metabolic pathways/gene networks. *Prerequisites: BENG 181 or BIMM 181 or CSE 181; BENG 182 or BIMM 182 or CSE 182 or CHEM 182; Bioinformatics majors only.* (W)

186A. Principles of Biomaterials Design (4)
Fundamentals of materials science as applied to bioengineering design. Natural and synthetic polymeric materials. Materials characterization and design. Wound repair, blood clotting, foreign body response, transplantation biology, biocompatibility of materials, tissue engineering. Artificial organs and medical devices. Government regulations. Patenting. Economic impact. Ethical issues. A term project and oral presentation are required. *Prerequisite: grade of C– or better in BENG 112B or senior standing in Bioengineering: Biotechnology major; majors only or consent of department.* (F)

186B. Principles of Bioinstrumentation Design (4)
Biophysical phenomena, transducers, and electronics as related to the design of biomedical instrumentation. Potentiometric and amperometric signals and amplifiers. Biopotentials, membrane potentials, chemical sensors. Electrical safety. Mechanical transducers for displacement, force, and pressure. Temperature sensors. Flow sensors. Light-based instrumentation. *Prerequisites: grade of C– or better in MAE 140 and MAE 170.* (W)

186C. Bioengineering Design (4)
Development of an original bioengineering design described in a formal engineering report, leading to a major and complete design experience. Emphasis on engineering analysis and application of methodology from various branches of applied mechanics. Includes analysis of economic, environmental, manufacturability, ethical, health and safety, social, political issues, and application of governmental regulations. A term project and oral presentation are required. *Prerequisites: grades of C– or better in BENG 103B, BENG 106B, BENG 112B, and BENG 186B; CENG 101A, MAE 107 and MAE 130A; majors only.* (S)

191. Senior Seminar I: Professional Issues in Bioengineering (2)
Role of bioengineers in industry. Professional identity. Structure of bioengineering industries and product development process. Job market analysis. Current employment opportunities. Recruiting process and interview. Analysis of the employer. Marketing vs. engineering. Management by objective. Role of higher degrees. *Prerequisite: consent of instructor.* (W)

195. Teaching (2-4)
Teaching and tutorial assistance in a bioengineering course under supervision of instructor. Not more than four units may be used to satisfy graduation requirements. (P/NP grades only.) *Prerequisites: B average in the major and departmental approval.* (F,W,S)

196. Bioengineering Industrial Internship (1-4)
Under the joint supervision of a faculty adviser and industry mentor, the student will work at a bioengineering industrial site to gain practical bioengineering experience. No more than twelve units may be used to satisfy graduation unit requirements. (P/NP grades only) *Prerequisites: consent of department and completion of all lower-division course requirements, including general-science requirements. Some laboratory experience is needed. Completion of ninety units with a 2.5 GPA and consent of a bioengineering faculty coordinator.* (F,W,S,Su)

197. Engineering Internship (1-4)
An enrichment program, available to a limited number of undergraduate students, which provides work experience with industry, government offices, hospitals, and their practices. Subject to the availability of positions, students will work in a local industry or hospital (on a salaried or unsalaried basis) under the supervision of a faculty member and industrial supervisor. Coordination of the Engineering Internship is conducted through UCSD's Academic Internship Program. Time and effort to be arranged. Final report required. *Prerequisites: completion of ninety units with a 2.5 GPA and consent of a bioengineering faculty coordinator.* (F,W,S,Su)

198. Directed Group Study (1-4)
Directed group study, on a topic or in a field not included in the regular department curriculum, by arrangement with a bioengineering faculty member. (P/NP grades only.) *Prerequisites: consent of instructor; upper-division standing, completion of ninety units of UCSD undergraduate study, a minimum UCSD GPA of 2.5, and a completed and approved "Special Studies" form, "Application for UCSD Special Studies Course Enrollment."* (F,W,S)

199. Independent Study for Undergraduates (4)
Independent reading or research by arrangement with a bioengineering faculty member. (P/NP grades only.) *Prerequisites: consent of instructor; upper-division standing, completion of ninety units of UCSD undergraduate study, a minimum UCSD GPA of 2.5, and a completed and approved "Special Studies" form, "Application for UCSD Special Studies Course Enrollment."* (F,W,S,Su)

GRADUATE

202/CSE 257A. Bioinformatics II: Sequence and Structure Analysis—Methods and Applications (4)
Introduction to methods for sequence analysis. Applications to genome and proteome sequences. Protein Structure, sequence-structure analysis. *Prerequisite: Pharm. 201 or consent of instructor.* (W)

203. Bioinformatics III: Genomes Analysis (4)
Annotating genomes, characterizing functional genes, profiling, reconstructing pathways. *Prerequisites: Pharm. 201, BENG 202/CSE 257A or consent of instructor.* (S)

207. Topics in Bioengineering (4)
Course given at the discretion of the faculty on current topics of interest in bioengineering. (F,W,S)

208. Topics in Bioengineering with Lab (2 or 4)
A course to be given at the discretion of the faculty on topics of current interest in engineering science. This course is intended to be a lecture and lab companion topics course. *Prerequisite: consent of instructor.* (S)

BENG 209. Continuum Mechanics Applied to Medicine/Biology
Introduction to the basic definitions of Continuum Mechanics and their mathematical formulation at the graduate level with applications to problems in medicine and biology. This course is intended for students with little or no background in mechanics; it is an introduction to the Biomechanics courses BENG 250 A-B in the Department of Bioengineering and to Solid and Fluid Mechanics courses MAE 210A and MAE 231A in the Department of Mechanical and Aerospace Engineering. This course should NOT be

taken concurrently with MAE 210A or MAE 231A. *Prerequisite: consent of instructor.* (F)

BENG 211. Systems Biology and Bioengineering I: Biological Components
Components of biological systems, their biochemical properties and function. The technology used for obtaining component lists. Relationship within and integration of component lists. Structured vocabularies and component ontologies. Algorithms for comparative approaches in deciphering and mining component lists. *Prerequisite: BENG 230A or BIMM 100 or consent of instructor.* (F)

BENG 212. Systems Biology and Bioengineering II: Network Reconstruction
This course will cover the process of reconstructing complex biological reaction networks. Reconstruction of metabolic networks, regulatory networks and signaling networks. Bottom-up and top-down approaches. The use of collections of historical data. The principles underlying high-throughput experimental technologies and examples given on how this data is used for network reconstruction, consistency checking, and validation. *Prerequisite: BENG 211 or consent of instructor.* (W)

BENG 213. Systems Biology and Bioengineering III: Building and Simulating Large-scale In Silico Models
Mathematical models of reconstructed reaction networks and simulation of their emergent properties. Classical kinetic theory, stochastic simulation methods and constraints-based models. Methods that are scalable and integrate multiple cellular processes will be emphasized. Existing genome-scale models will be described and computations performed. Emphasis will be on studying the genotype-phenotype relationship in an in silico model driven fashion. Comparisons with phenotypic data will be emphasized. *Prerequisite: BENG 212 or consent of instructor.* (S)

220. Project Design and Development (4)
The design of a research/development project for an industrial setting. Project objectives and organization, funding sources, review of previous developments in the area, proposal writing and review, project management, intellectual property, regulatory issues. The term project will involve preparing a small business proposal for development of a medical device. *Prerequisite: open to students with graduate standing in bioengineering.* (W)

225. BioBusiness: Starting, Growing, and Harvesting a Biotech Company
Biotech is a special breed of business, especially in the start-up and early phases. Whether you are considering joining a biotech start-up or want to be successful in a life science organization, it pays to understand this unique business model. In this course, you will study and analyze (1) start-up proposals (2) the genesis of the biotech industry (3) biotech categories and growth strategies (4) the process of spinning out viable product concepts from academia (5) financing techniques (6) business development (7) acquisition/IPO valuation methods (8) potentially disruptive technologies. The format is highly interactive and learning is enhanced by means of exercises, team presentations, and case studies. Prerequisites: for bioengineering MEng degree students or consent of instructor. (F,W)

230A. Biochemistry (4)
A graduate course in biochemistry especially tailored to the requirements and background of bioengineering graduate students. It will cover the important macro- and small molecules in cells that are the major constituents, or that function as signaling molecules or molecular machineries. The structures, pathways, interactions, methodologies, and molecular designs using recombinant DNA technology will be covered. *Prerequisites: BIPN 100 and 102, or consent of instructor.* (F)

230B. Cell and Molecular Biology (4)
A general survey of structure-function relationships at the molecular and cellular levels. Emphasis on basic genetic mechanisms; control of gene expression; membrane structure, transport and traffic; cell signaling; cell adhesion; mechanics of cell division; and cytoskeleton. *Prerequisites: BIPN 100 and 102, and BENG 230A, or consent of instructor.* (W)

230C. Cardiovascular Physiology (4)
Physical concepts of behavior of heart, large blood vessels, vascular beds in major organs and the microcirculation. Physical and physiological principles of blood flow, blood pressure, cardiac work, electrophysiology of the heart. Special vascular beds, including their biological and hemodynamic importance. Integration through nervous and humoral controls. *Prerequisites: BIPN 100 ,102 , and BENG 230B, or consent of instructor.* (S)

230D. Respiratory and Renal Physiology (4)
Mechanics of breathing. Gas diffusion. Pulmonary blood flow. Stress distribution. Gas transport by blood. Kinetics of oxygen and carbon dioxide exchange. VA/Q relations. Control of ventilation. Glomerular and proximal tubule functions. Water metabolism. Control of sodium and potassium in the kidney. *Prerequisites: BIPN 100 ,102 , and BENG 230C, or consent of instructor.* (F,W,S)

238. Molecular Biology of the Cardiovascular System (4)
This course will give an overview of heart and vascular development and disease from a molecular biological perspective. Current approaches for generating mouse models of cardiovascular disease and recently developed technologies for physiological assessment in small animal models will be presented. (S)

241A. Foundations of Tissue Engineering Science (4)
Molecular and cell biological basis of tissue engineering science. Paracrine control of tissue growth and differentiation. Biomechanics and the molecular basis of cell-cell and cell-matrix interactions. Cell motility, mechanics of tissue growth and assembly, tissue repair. Mass transfer in tissues. Microcirculation of blood and lymph. *Prerequisite: BENG 230A or consent of instructor.* (S)

241B. Methods in Tissue Engineering Science (4)
Isolation of cells, cell and tissue culture systems. Fluorescence and confocal microscopy. Intracellular imaging. Mechanical testing of tissues. Micromechanical measurement and analysis of cell deformability and cell interaction. Methods in microcirculation and angiogenesis. *Prerequisite: BENG 241A or consent of instructor.* (F)

241C. Applications of Tissue Engineering Science (4)
A lecture/seminar series featuring speakers from academia and industry emphasizing principles of tissue engineering science as applied to clinical medicine and industrial production. Topics include skin replacement, guide tubes for nerve regeneration, blood substitutes, pancreatic islet replacement, and drug delivery devices, among others. Ethics of tissue replacement. *Prerequisite: BENG 241B or consent of instructor.* (W)

BENG 247A. Advanced BioPhotonics
Basic physics and chemistry for the interaction of photons with matter, including both biological and synthetic materials; use of photonic radiation pressure for manipulation of objects and materials; advanced optoelectronic detection systems, devices and methods, including time resolved fluorescent and chemiluminescent methods, fluorescent energy transfer (FRET) techniques, quantum dots, and near-field optical techniques; underlying mechanisms of the light sensitive biological systems, including chloroplasts for photosynthetic energy conversion and the basis of vision processes. *Prerequisite: graduate standing.* (F)

BENG 247B. BioElectronics
Topics to be covered will include photolithographic techniques for high-density DNA microarray production, incorporation of CMOS control into electronic DNA microarrays, direct electronic detection technology used in microarrays and biosensor devices, and focus on problems related to making highly integrated devices (lab-on-a-chip, *in vivo* biosensors, etc.) form heterogeneous materials and components. *Prerequisite: graduate standing*. (W)

BENG 247C. Bionanotechnology
Topics include: nanosensors and nanodevices for both clinical diagnostics and biowarfare (bioterror) agent aetection; nanostructures for drug delivery; nanoarrays and nanodevices; use of nanoanalytical devices and systems; methods and techniques for modification or functionalization of nanoparticles and nanostructures with biological molecules; nanostructural aspects of fuel cells and biofuel cells; potential use of DNA and other biomolecules for computing and ultra-high-density data storage. *Prerequisite: graduate standing.* (S)

250A. Biomechanics (4)
An introduction to biomechanics and transport phenomena in biological systems at the graduate level. Biorheology, biosolid mechanics, muscle mechanics, mass transfer, momentum transfer, energy transfer. *Prerequisites: CENG 103B and BENG 112B, or consent of instructor.* (W)

250B. Advanced Biomechanics (4)
Modern development of biomechanics at an advanced mathematical level. Selected topics in the dynamics of heart, pulsatile, blood flow, microcirculation, and muscle mechanics. *Prerequisite: BENG 253 or consent of instructor.* (S)

253. Biomedical Transport Phenomena (4)
Nonequilibrium thermodynamic analysis of transport phenomena. The osmotic effect. Diffusion and exchange in biological systems. *Prerequisite: consent of instructor.* (W)

264. Advanced Biomedical Transport Phenomena (4)
Applications of heat, mass, and momentum transfer in biomedical systems. Extension of the principles encountered in BENG 252B-C to practical biomedical systems. *Prerequisite: BENG 252B-C.*

267. Microcirculation in Health and Disease (4)
Structural and functional aspects of transport and blood-tissue exchange in key organs during circulatory shock, bacterial toxemia, hypertension. Physical and ultrastructural techniques used to analyze small-vessel dynamics. *Prerequisite: consent of instructor.*

275. Computational Biomechanics (4)
Finite element methods for anatomical modeling and boundary value problems in the biomechanics of tissues and biomedical devices. Nonlinear biodynamics, heat flow, cardiac impulse propagation, anatomic modeling, and biomechanics. *Prerequisite: consent of instructor.* (F)

BENG 280A. Principles of Biomedical Imaging
Fundamentals of Fourier transform and linear systems theory including convolution, sampling, noise, filtering, image reconstruction and visualization with an emphasis on applications to biomedical imaging. Examples from optical imaging, CT, MR, ultrasound, nuclear, PET, and radiography. *Prerequisite: consent of instructor.* (F)

BENG 280B. Comparative Biomedical Imaging
Application of biomedical imaging to the measurement of structure, function, and dynamics of organ systems from the microscopic to the organ level. Emphasis on detailed evaluation and comparison of specific imaging modalities. *Prerequisite: consent of instructor.* (W,S)

281. Seminar in Bioengineering (1)
Weekly seminars by faculty, visitors, postdoctoral research fellows, and graduate students concerning research topics in bioengineering and related subjects. May be repeated for credit. This course does not apply toward the M.S. graduation requirements. (S/U grades only.) (F,W,S)

290. Bioengineering Special Graduate Seminar (1-2)
Seminars by faculty, visitors, post-doctoral research fellows, and/or graduate students in selected topic(s) in bioengineering and/or related subjects. This course does not apply toward M.S. graduation requirements.

295. Bioengineering Design Project and Industrial Training (4)
Independent work by graduate students focused on design, applied research, and professional experience. *Prerequisite: consent of department and bioengineering faculty adviser.* (F,W,S)

296. Independent Study (4)
Prerequisite: consent of instructor.

298. Directed Group Study (1-4)
Directed group study on a topic or in a field not included in regular department curriculum, by special arrangement with a faculty member. *Prerequisite: consent of instructor.* (S/U grade only.)

299. Graduate Research (1-12)
(S/U grades only.)

501. Teaching Experience (2)
Teaching experience in an appropriate bioengineering undergraduate course under direction of the faculty member in charge of the course. Lecturing one hour per week in either a problem-solving section or regular lecture. (S/U grade only.) *Prerequisites: consent of instructor and departmental approval.* (F,W,S)