Bioengineering

STUDENT AFFAIRS:
4103 Engineering Building I, Warren College
http://www-bioeng.ucsd.edu/homepage.html

Professors

S. Chien, M.D., Ph.D., *Director, Whitaker Institute for Biomedical Engineering*
J. A. Frangos, Ph.D.
Y. C. Fung, Ph.D., *Professor Emeritus*
D. A. Gough, Ph.D., *Chair*
M. Intaglietta, Ph.D.
A. D. McCulloch, Ph.D.
B. O. Palsson, Ph.D.
G. W. Schmid-Schoenbein, Ph.D.
S. Subramaniam, Ph.D.

Associate Professors

R. L. Sah, M.D., Sc.D.
L. A. Sung, Ph.D.

Assistant Professors

G. A. Huber, Ph.D.
S. Bhatia, M.D., Ph.D.

Adjunct Professors

M. Berns, Ph.D., *Adjunct Professor*
L. Bjursten, Ph.D., *Adjunct Professor*
P. C. Johnson, Ph.D., *Adjunct Professor*
T. D. Pollard, Ph.D., *Adjunct Professor*
D. A. MacKenna, *Assistant Adjunct Professor*
J. Penhune, Ph.D., *Adjunct Professor*
S. S. Sobin, M.D., Ph.D., *Adjunct Professor*
L. K. Waldman, Ph.D., *Associate Adjunct Professor*
J. T. Watson, Ph.D., *Adjunct Professor*
R. Winslow, Ph.D., *Adjunct Professor*

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, Medicine*
M. H. Ellisman, Ph.D., *Professor, Neurosciences*
A. Fronek, M.D., Ph.D., *Professor Emeritus, Surgery*
A. Hoger, Ph.D., *Professor, Mechanical and Aerospace Engineering*
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. Baker, Ph.D., *Assistant Research Scientist*
A. Chen, Ph.D., *Assistant Project Scientist*
P. C. Chen, Ph.D., *Assistant Project Scientist*
K. Francis, Ph.D., *Assistant Project Scientist*
Y. L. Hu, Ph.D., *Assistant Project Scientist*
W. Huang, Ph.D., *Assistant Project Scientist*
Y. S. Li, Ph.D., *Assistant Project Scientist*
D. Lim, Ph.D., Sc.D., *Research Scientist*
G. Kassab, Ph.D., *Associate Research Scientist*
J. Price, M.D., Ph.D., *Associate Research Scientist*
A. Tsai, Ph.D., *Associate Research Scientist*
S. Usami, M.D., Ph.D., *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.

At the undergraduate level, the department offers a four-year engineering curriculum leading to a **B.S. in bioengineering**, which prepares students for careers in the biomedical industry or for further education in graduate school. Students completing the B.S. in bioengineering have sufficient preparation in mechanics to permit employment in traditional engineering areas other than the biomedical industry, if they wish. This degree is accredited by the Accreditation Board for Engineering and Technology (ABET).

The department also offers a two-year, upper-division curriculum which, together with required lower-division courses, leads to a **B.S. in premedical bioengineering**. 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. 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 jobs in industry.

In addition, the department offers a **B.S. in biotechnology**. This is a four-year engineering curriculum that prepares students for careers in the emerging biotechnology industry or for further education in graduate school. This curriculum has a strong engineering foundation with emphasis on biochemical process applications. ABET accreditation will be sought for this major.

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.** 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.** and **M.D./Ph.D.** degrees offered in conjunction with UCSD Medical School, pending independent admission to the Medical School. In addition to the existing M.S. degree, the department offers a master of engineering (**M.Eng.**) degree. The M.Eng. is a terminal professional degree whereas the M.S. and Ph.D. 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 curricular track 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 the department requires 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. The B.S. in bioengineering, the B.S. in premedical bioengineering, and the B.S. in biotechnology require a completion of a minimum of 192 units.

Deviations from the required programs of study must be approved by the Undergraduate Affairs 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 program, TE courses are restricted to those that meet ABET standards. Courses such as Bioengineering 196, 197, and 198 are not allowed as technical electives in meeting the upper-division major requirements. 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 upon 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, but most bioengineering upper-division courses are taught only once each year. **Deviations in the scheduling of upper-division bioengineering courses are discouraged, as such changes usually lead to a delay in graduation.** The curricula shown in the tables below are consistent with present scheduling.

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 college to which the student belongs, as well as the major requirements determined by the department. The five 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 program, 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 and biotechnology curriculum tables. Accordingly, students in these colleges may take longer to graduate than as indicated in the four-year schedule. Students must consult with their college to determine which HSS courses to take.

BIOENGINEERING

(ABET Accredited Program)

FALL	WINTER	SPRING
FRESHMAN YEAR		
Math. 20A*	Math. 20B*	Math. 21C*
MAE 9 or 10*	Phys. 2A*	Phys. 2B*/2BL
Chem. 6A*	Chem. 6B/6BL	BILD 1
HSS[1]	BE 1[2]	HSS
	HSS	
SOPHOMORE YEAR		
Math. 21D	Math. 20F	Math. 20E
Phys. 2C/2CL	MAE 140	BE 100
MAE 130A/SE 101A	BE 106B	MAE 3
HSS	HSS	HSS
JUNIOR YEAR		
BE 110	BE 112A	BE 112B
MAE 107	BE 186B	BE 172
CENG 103A	HSS	BE 140B
MAE 170	BE 140A	BE 103B
SENIOR YEAR		
BE 186A	BE 122A	BE 186C
TE[3]	MAE 150	BE 122B
MAE 105	HSS	HSS
HSS	BE 191[4]	TE
TE	BE 130	

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

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

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

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

[4] Recommended course, not required. Graduating seniors only.

BIOTECHNOLOGY

FALL	WINTER	SPRING
FRESHMAN YEAR		
Math. 20A*	Math. 20B*	Math. 21C*
MAE 9 or 10*	Phys. 2A*	Phys. 2B*
Chem. 6A*	Chem. 6B/6BL	Chem. 6C
HSS[1]	HSS	HSS
	BE 1[2]	
SOPHOMORE YEAR		
Math. 21D	Math. 20F	Math. 20E
BILD 1	Phys. 2C/2CL	HSS
Chem. 140A	Chem. 140B	Chem. 143A
HSS	BE 130	BE 100
JUNIOR YEAR		
BIBC 100	BIBC 102	BIBC 103
CENG 103A	HSS	BE 103B
MAE 140	CENG 100	BIMM 100
BICD 100	BE 122A	HSS
SENIOR YEAR		
BE 186A	HSS	BE 160C
BE 160A	BE 160B	TE[4]
MAE 170	BE 166A	BE 162
HSS	BE 191[3]	HSS

* Students are admitted by departmental approval during the sophomore year based upon these screening courses and others listed on the department's application form.

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

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

[3] Recommended course, not required. Graduating seniors only.

[4] Technical electives must be selected from a departmental approved list. Consult the Student Affairs Office.

PREMEDICAL BIOENGINEERING

FALL	WINTER	SPRING
FRESHMAN YEAR		
Math. 20A*	Math. 20B*	Math. 21C*
MAE 9 or 10*	Phys. 2A*	Phys. 2B*/2BL
Chem. 6A*	Chem. 6B/6BL	Chem. 6C
HSS[1]	BE 1[2]	HSS
	HSS	

SOPHOMORE YEAR		
Math. 21D	Math. 20F	Math. 20E
Phys. 2C/2CL	Chem. 140A	BE 100
BILD 1	BILD 2	Chem. 140B
HSS	HSS	HSS
JUNIOR YEAR		
BE 110	BE 112A	BE 112B
Chem. 143A	MAE 140	MAE 170
Chem. 140C[3]	BICD 100	BIBC 100
HSS	HSS	HSS
SENIOR YEAR		
BE 186A	BE 186B	BE 172
BIPN 140	BIPN 100	BIPN 102
TE[4]	TE	TE
HSS	HSS	HSS

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

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

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

[3] 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.

[4] Technical elective (TE) courses must be upper-division or graduate courses in the engineering sciences, natural sciences or mathematics, selected with prior approval of the department.

Policies and Procedures

Application for Admission to the Bioengineering Majors

Because of the strong student interest in the bioengineering programs and the limited resources available to accommodate this demand, it is necessary to limit enrollments to only the most qualified students. Admission to the department as a bioengineering major is in accordance with the general requirements established by the School of Engineering described in detail in the section on "Admission to the School of Engineering" in this catalog.

Applicants who have demonstrated excellent academic performance prior to being admitted to UCSD may be admitted directly to the bioengineering or bioengineering: premedical major. At this time, students are admitted to the biotechnology major by departmental approval only. Other students intending to complete a bioengineering major are initially identified as pre-bioengineering majors and may be admitted by petition to the department based on academic performance. It is expected that students will have completed or have in progress all eight prerequisite courses when applying. Each petition is evaluated by the departmental Undergraduate Affairs Committee, taking into consideration the student's entire academic record. Pre-bioengineering majors who have achieved a GPA of 3.0 or better in the eight required pre-bioengineering courses (Mathematics 20A-B, 21C; Physics 2A-B; Chemistry 6A; MAE 9/10 and one other pre-bioengineering course by the end of the freshman year) are assured of admission. Students not admitted to a major by the end of the freshman year must reapply before the end of the sixth quarter of study at UCSD. Pre-bioengineering students not obtaining admission to a bioengineering major will automatically have their major converted from "Pre-bioengineering" to "Undeclared" by the department at the end of the sixth quarter. All students, regardless of admission route, are expected to complete lower- and upper-division courses given in the curriculum tables in a timely fashion in the sequences outlined.

Transfer Students

Transfer students may apply for admission to any of the bioengineering undergraduate tracks. Transfer students may apply for admission before the end of the first quarter of study at UCSD and must complete at least ten required pre-bioengineering or bioengineering courses, two of which must be taken at UCSD, one of which must be an upper-division course. Accordingly, when planning their program, transfer students should be mindful of lower-division prerequisite course requirements upon which admission to the major is based, as well as meeting college requirements. Students who have taken equivalent courses elsewhere may request to have transfer credit applied toward the department's major requirements. This is done by submitting a petition for transfer credit together with a transcript and catalog course description from the institution where the course(s) were taken. These documents are reviewed for approval by the Bioengineering Undergraduate Affairs Committee. Transfer petitions are available from the Student Affairs Office.

Academic Advising

Upon admission to the major, students must make an appointment with an undergraduate adviser in the Bioengineering Student Affairs Office, Room 4103, Engineering Building Unit 1, to plan a program of study. The program plan may be revised in subsequent years, but revisions involving curricular requirements require approval of the undergraduate adviser and the Undergraduate Affairs 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.

In order 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 declared pre-engineering students and/or to students who have been admitted to a bioengineering 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.

Pre-bioengineering majors can obtain programmatic advice from the Student Affairs Office. In addition, technical advice may be obtained from a specific bioengineering faculty member. A bioengineering faculty adviser is assigned to each student upon admission to the major.

Program Alterations and Exceptions to Requirements

Variations from or exceptions to any program or course requirements are possible only if approved by the Undergraduate Affairs Committee before the courses in question are taken. Petition forms may be obtained from the Bioengineering Student Affairs Office.

Bioengineering students may take Bioengineering 199, Independent Study for Undergraduates, under the guidance of a bioengineering faculty member. This course is taken as an elective on a P/NP basis. Under certain conditions, however, it 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 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 form to the Undergraduate Affairs Committee. These forms must be completed, approved, and processed **prior** to the beginning of the quarter in which the course is to be taken. This should not be done during the add/drop period. Detailed policy in this regard may be obtained from the Student Affairs Office.

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 (4110 Engineering Building 1, Warren College) 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., Ph.D., and 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. In addition, for M.Eng. applicants attention will be paid to the background and statement of purpose to ensure that they match the goal 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 correspondingly well-suited to the M.Eng. program. A minimum score of 550 (paper-base) or 213 (computer base) 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.) Applicants are judged competitively. 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 UC Extension's concurrent registration program, but such enrollment in a bioengineering graduate course must be approved by the instructor.

Master's 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. Ph.D. students may obtain the M.S. degree by completing the course requirements of the M.S. degree and by passing the Ph.D. departmental examination provided that the student does not already hold a M.S. degree in engineering. The M.S. degree program involves a combination of course work and original research.

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 (nine courses) in course work and twelve units of Bioengineering 299 to fulfill the research requirement. 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

Biomechanics and Transport Phenomena

BE 250A. Biomechanics

BE 250B. Advanced Biomechanics

BE 253. Biomedical Transport Phenomena

Quantitative Physiology

BE 230A. Biochemistry

BE 230B. Cell and Molecular Biology

BE 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.

MASTERS 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 intervene and 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. See following section on **Change of Degree Aim.**

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.

In addition to the existing M.S. degree, 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 BE 295 *Bioengineering Design Project* 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 bioenginering 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 two three-course sequences (**six** courses) from the three 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. 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 (Two three-course sequences required)

Biomechanics and Transport Phenomena—BE 250A-B, 253
Tissue Engineering—BE 241A-B-C
Quantitative Physiology—BE 230A-B-C

Example 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)

BE 160A-B-C. Biochemical Engineering
IR/PS Management: IPGN 438, 439, 442, 444, 445, 420, 434, IPCO 420, 421
IR/PS International Issues: IPCO 401, IPGN 407, 411, 413, 418
MAE 133. Finite Element Method
Phys. 206. Biophysics

Sample M.Eng. Program of Study

FALL	WINTER	SPRING
BE 230A	BE 230B	BE 230C
Tech Elec	BE 250A	BE 250C
Gen Elec	BE 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 and is usually scheduled in the month of July. The exam is designed to ensure that all successful candidates possess a strong command of the engineering and life science subjects that form the foundations of bioengineering research 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 oral examination is based on the following three subject areas at the graduate engineering level which ensures adequate breadth:

1. **Engineering Foundations**

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

   CSE 202. Algorithm Design and Analysis
   ECE 222A. Applied Electromagnetic Theory
   ECE 251AN. Digital Signal Processing
   ECE 270A-B-C. Neurocomputing
   MAE 210A. Fluid Mechanics
   MAE 221A. Heat and Mass Tranfer
   MAE 223. Computational Fluid Dynamics
   MAE 227. Structure and Bonding of Solids
   MAE 231A. Foundations of Solid Mechanics
   MAE 252. Chemical Reaction Engineering
   MAE 280A. Linear Systems Theory
   MAE 281A. Nonlinear Systems
   MAE 290A. Numerical Methods in Science and Engineering

   Other topics may be approved by the Graduate Studies Committee

2. **Biomechanics and Transport Phenomena**

   Defined by the content of the following three bioengineering courses:

   BENG 250A. Biomechanics
   BENG 250B. Advanced Biomechanics
   BENG 253. Biomedical Transport Phenomena

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
   CHEM 211. Metabolic Biochemistry or BENG 230A. 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 and other bioengineering graduate course sequences.
   - One quarter of BENG 501 Teaching Experience
   - BENG 281 Seminar in Bioengineering (F,W,S)

Courses comprising the departmental qualifying examination 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 of a plan for the thesis research project. The committee may ask questions directly or indirectly related to the project and general questions that it determines to be relevant. 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 2001–2002 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.
If the class is full, please place your name on the waitlist and attend the first class meeting.

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).

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)

UPPER-DIVISION

100. Introduction to Bioengineering (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: grade of C– or better in Math. 21C or Math. 20C and Math. 21D or Math. 20D, and Phys. 2C; majors only.* (S)

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. *Prerequisites: CENG 103A with grade of C– or better; 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. Bionegineering design problems, problem formulation, and problem solutions. *Prerequisites: Math. 21D and MAE 130A/SE 101A with grade of C– or better; 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: admission to the major and grades of C– or better in Phys. 2A-C.* (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 BE 110; majors only.* (W)

112B. Biomechanics (4)
Basic mechanical properties of collagen and elastin, bone, cartilage, muscles, blood vessels, and other living tissues. Application of continuum mechanics to hard and soft tissues. Biomechanical engineering design for clinical applications. *Prerequisites: grade of C– or better in BE 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 control of first and second order processes. PID controllers. Stability. Bode design. Features of biological control systems. A simulation term project using MATLAB and an oral presentation are required. *Prerequisites: grade of C– or better in MAE 105; majors only or junior standing in the biotechnology major 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)

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. *Prerequisites: grade of C– or better in Chem. 6B, Math. 20A-B, Physics 2A-2C. Physics 2C may be taken concurrently; majors only.* (W)

140A. Bioengineering Physiology (4)
Introductory mammalian physiology for bioengineering students, with an 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. *Prerequisites: grade of C– or better in Chem. 6A and 6B, Physics 2A-B-C, BILD 1.* (W).

140B. Bioengineering Physiology (4)
Introductory mammalian physiology for bioengineering students, with an emphasis on control mechanisms and engineering principles. Digestive, respiratory, renal, and reproductive systems; regulation of metabolism, and defense mechanisms. *Prerequisite: grade of C– or better in BE 140A; majors only*. (S).

160A. Metabolic Engineering (4)
Engineering systems analysis of metabolic processes common to all living organisms. Kinetics of individual enzymatic reactions. Computer simulations of metabolic networks. The stoichiometric matrix, systemic sensitivity coefficients, bifurcations and redirection of metabolic fluxes. Temporal decompositions of metabolic processes into multiple time scales and the physiologic roles of metabolic events in each scale. *Prerequisites: grade of C– or better in BIBC 102 (may be concurrent), BE 122A and admission to the major*. (F)

160B. Biochemical Engineering (4)
Industrial microbial production strains, bioreactor and fermenter designs, bioprocess monitoring and control. *Prerequisite: BE 160A; majors only*. (W)

160C. Biochemical Engineering (4)
Bioseparations. Commercial production of biochemical commodity products. *Prerequisite: BE 160B; 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, BE 160B.* (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, extracellular matrix, and growth factor communication. The design of functional tissue units. Clinical Applications. *Prerequisite: admission to the major or consent of department*. (W)

172. Bioengineering Laboratory (4)
A laboratory course which demonstrates basic concepts of bioengineering design through experimental procedures involving humans and experimental 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)

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. Ethical issues. A term project and oral presentation are required. *Prerequisite: grade of C– or better in BE 112B or senior standing in the biotechnology major 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. Mechanical transducers for displacement, force and pressure. Temperature sensors. Flow sensors. Light-based instrumentation. Electrical safety. A term project and oral presentation are required. *Prerequisites: grade of C– or better in MAE 140 and 170.* (W)

186C. Bioengineering Design (4)
Preparation of formal engineering reports on a series of engineering analysis and design problems illustrating methodology from various branches of applied mechanics as applied to bioengineering problems. Statistical analysis. Governmental regulations. Bioethical issues. A term project and oral presentation are required. *Prerequisites: grades of C– or better in CENG 103A-B, MAE 107, MAE 130A-B, BE 112B, and 186B; 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. Units may not be applied towards major graduation requirements unless prior approval of a faculty advisor is obtained and internship is an unsalaried position. *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.) *Prerequisite: consent of instructor.* (F,W,S)

199. Independent Study for Undergraduates (4)
Independent reading or research by arrangement with a bioengineering faculty member. (P/NP grades only.) *Prerequisite: consent of instructor.* (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.

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.*

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

220. Project Desing 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.

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 BE 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 BE 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 BE 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: BE 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: BE 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: BE 241B or consent of instructor.* (W)

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 BE 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: BE 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 BE 252B-C to practical biomedical systems. *Prerequisite: BE 252B-C.*

266. Methodology for Single Cell Studies (4)
Technology for the characterization and measurement of biophysical properties of single live cells. Imaging techniques. Membrane mechanics. Mechanical and fluid mechanical manipulation. Electrodes and electrical methods. Flow and image cytometry. Automated cell recognition and sorting. *Prerequisite: consent of instructor.*

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.*

268. Blood Substitutes (4)
Principles of oxygen transport to tissue and transfusion physiology. Development and clinical use of artificial oxygen carriers, i.e., blood substitutes. Physiology of tissue oxygenation. Current developments. Experimental models for the study of oxygen transfer and measurement techniques. Medical applications. *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.*

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 Indusrial 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.*