School of Biomedical ENGINEERING

PhD-Bioengineering
Curriculum Requirements & Course Information

Curriculum Requirements:

The following lists the specific requirements for the Doctor of Philosophy degree. (Students must be able to answer yes to the following statements to earn a Ph.D at CSU.):

- Minimum of 72 semester credits of graduate work in approved course of study.
- Minimum of 32 semester credits earned after admission to CSU.
- 10 credits earned after Master's degree may be transferred for credit with approval from the students major advisor, the School of Biomedical Engineering, and the Graduate School.
- Minimum of 12 semester credits in 500 level (and above) formally taught courses (not including dissertation and independent study) earned at CSU (post Master's degree).
- Give a seminar on their research every other year. These seminar requirements are in addition to the dissertation requirements (as specified by the Graduate School).
- The listed electives are a suggestion and not exclusive. It is strongly recommended, but at the advisor's discretion, that at least six credits of technical electives must be from within the College of Engineering and six credits must be from the Life Sciences.
- Successful completion of the Qualifying Process.
- Successful completion of the Preliminary Exam.
- Successful completion of the Dissertation Defense.

Students will be actively involved and engaged with the development of cutting-edge technologies in this research-based curriculum. As with most science and technology-related graduate programs, many of the career development tools will be derived from students attending and presenting at national and international meetings.

F=Fall **S**=Spring **SS**=Summer **E**=Even Years **O**=Odd Years

Core Courses

The following courses represent the core course requirements for the proposed graduate program. All PhD students are required to complete the core course requirements.

Course Number	Title	Credits	Prerequisite(s)	Semesters Taught	Catalog Description
STAT 511* or	Design and Data Analysis for Researchers I	4	STAT 301 or STAT 307 or STAT 311 or STAT 315	F	Statistical methods for experimenters and researchers emphasizing design and analysis of experiments.
STAT 512* or	Design and Data Analysis for Researchers II	4	STAT 511 or written consent of instructor	S	Statistical methods for experimenters and researchers emphasizing design and analysis of experiments.
STAT 520* or	Introduction to Probability Theory	4	MATH 229; MATH 261; MATH 317	F	Probability, random variables, distributions, expectations, generating functions, limit theorems, convergence, random processes.
STAT 521*	Stochastic Processes I	3	STAT 520	S	Characterization of stochastic processes, Markov chains in discrete and continuous time, branching processes, renewal theory, Brownian motion.
MATH 545	Partial Differential Equations I	3	MATH 340 or MATH 345 or MATH 530.	F	Second order linear PDEs, elliptic and parabolic equations, equations of math physics, separation of variables, Fourier series.
BIOM/ECE 533**	Biomolecular Tools for Engineers	3	Written consent of the instructor.	F	Basic qualitative and quantitative biomolecular analyses of microbial communities, including PCR, cloning, FISH, and microbial community profiling. The application of biomolecular tools to engineered systems will be a major theme.
BIOM/MECH 570	Bioengineering	3	BMS 300	F	Introduction to the various fields within bioengineering, includes research lectures from expert guest lecturers and significant engineering content.
BIOM 592	Seminar	1 x 4 sems.	Written consent of the instructor.	F, S	Student and research faculty presentations, guest and invited extramural speakers.
BIOM 799	Dissertation	Var.		F, S, SS	

**Students need to take only one Core STAT Course and may choose STAT 511, STAT 512, STAT 520, or STAT 521.*

***Students with a strong background in Cellular and Molecular Biology may substitute CM502 (Techniques in Cell and Molecular Biology).*

Technical Elective Courses

Doctoral students are strongly recommended to take six credits of engineering electives and six credits of life science electives (500 level or above) at the discretion of the Graduate Affairs Committee. Doctoral students financially supported for the first year PhD lab rotation RAs must register for BIOM 790 their first two semesters. The following course list is meant to illustrate the broad and diverse elective course offerings available to students enrolled in the proposed program. In addition, the School of Biomedical Engineering is continually adding courses.

Engineering Technical Electives (six credits minimum)					
Course Number	Title	Credits	Prerequisite(s)	Semesters Taught	Catalog Description
BIOM/MECH 525	Cell and Tissue Engineering	3	BMS 300 or NB 501 or BIO 310 or BC 351	S, E	Cell and tissue engineering concepts and techniques with emphasis on cellular response, cell adhesion kinetics, and tissue engineering design.
BIOM/ECE 526	Biological Physics	3	MATH 340 or MATH 345; PH 142 or PH 122	S	Mathematical and physical modeling of biological systems. Mass transport in cellular environments. Electrical/mechanical properties of biomolecules.
BIOM/MECH 531	Materials Engineering	3	MECH 331 or MECH 431	S	Structural engineering materials and their selection on basis of property, processing, and economic considerations.
BIOM/MECH 532	Material Issues in Mechanical Design	3	MECH 331	F	Failure mechanisms from materials viewpoint with emphasis on use in design. Fracture, creep, fatigue and corrosion.
BIOM 537	Biomedical Signal Processing	3	MATH 340 or ECE 311 or STAT 303	S	Measuring, manipulating, and interpreting biomedical signals.
BIOM/CBE 543	Membranes for Biotechnology and Biomedicine	3	CHEM341, CHEM343, CHEM 472 or equivalent, CBE 332 or equivalent	F	Polymeric membrane formation, modification, module design and applications to bioseparation and biomedical separations and tissue engineering.
BIOM/MECH 573	Structure and Function of Biomaterials	3	MECH 331	S	Structure-function relationships of natural biomaterials; application to analysis of biomimetic materials and biomaterials used in medical devices.
BIOM 581A1	Biofluid Mechanics	3	MECH 342 or CIVE 300, BMS 300 and PH 121 or PH 141 or BMS 420	S, E	Fluid dynamic concepts for understanding fluid motion caused by living organs/organisms and advances research applications.
BIOM/MECH 671	Orthopedic Tissue Biomechanics	3	CIVE 560	S	Linear elastic, finite deformation and viscoelastic theories applied to the mechanical behavior of orthopedic tissues (bone, tendon, cartilage).
BIOM/ECE 680A1	Methods in Nanoscale Biophysics	3	BIOM/ECE 526	S, E	
MECH 680A1	Advanced Computational Methods for Materials	3	CHEM 461 or MECH 331; CHEM 472 or CHEM 474 or MECH 337 or PH 361; MATH 340	S	Commonly used advanced computational methods in research in materials; first-principle calculations, molecular simulation, mesoscopic simulations.
CBE 501	Chemical Engineering Thermodynamics	3		F	Definition, correlation, and estimation of thermodynamic properties; nonideal chemical and physical equilibria.
CIVE 502	Fluid Mechanics	3	CIVE 300	F	Fundamental physical concepts of fluid mechanics; ideal and viscous fluid flows; boundary-layer concepts.
CIVE 560	Advanced Mechanics of Materials	3	CIVE 360	F	Analysis of stress and strain failure theory; selected topics in solid mechanics, plate analysis; introduction to elastic stability.
CIVE 565	Finite Element Method	3	MATH 340	S	Theory and application in elasticity, porous flow, heat conduction, and other engineering problems.

CIVE 662	Foundations of Solid Mechanics	3	CIVE 560, MATH 531	F	Analysis of stress and strain in solids emphasizing linear elasticity and plasticity; introductions to creep, viscoelasticity, and finite deformations.
CIVE 667	Advanced Structural Analysis	3	CIVE 566	S	Analysis program development, application of finite element analysis, computer-assisted analysis, introduction to nonlinear analysis.
ECE 504	Physical Optics	3	Graduate standing or ECE 341 and ECE 342	F	Classical optics from first principles; basic electromagnetic theory to wave and geometric guides.
ECE 506	Optical Interferometry and Laser Metrology	3	ECE 341; ECE 342; ECE 441	F	High resolution metrology techniques utilizing and interferometric sensors using lasers and other light sources.
ECE 514*****	Applications of Random Processes	3	ECE 303/STAT 303 with grade of C- or better; ECE 312 with grade of C- or better	F	Bit-error rates, signal-to-noise power ration, signal detection, signal estimation, Wiener filter, application.
ECE 520	Optimization Methods-Control and Communication	3	MATH 229; MATH 317	S	Linear and nonlinear optimization theory and methods; applications in systems, control, and communication.
ECE 569	Micro-Electro-Mechanical Devices	3	ECE 331 with grade of C- or better or MECH 344	S, E	Micro-electro-mechanical processes and applications in sensors, optics, and structures.
ECE 652	Estimation and Filtering Theory	3	ECE 342	S, O	Fundamental principles of short wavelength electromagnetic radiation.
MECH 524	Principles of Mechanics	3	MECH 324	F	Kinematics and dynamics of rigid body motion; Lagrangian and Hamiltonian formulations of mechanics; applications to engineering problems.
MECH 530	Advanced Composite Materials	3	CIVE 360, MECH 331	F	Materials aspects of advanced composite constituents and how their combination yields synergistic results.
Cannot count as Engineering Technical Elective if student took or plans to take STAT 521 as core course or as an elective.					
Life Science Technical Electives (six credits minimum)					
BC 512	Principles of Macromolecular Structure	1	BC 411 or concurrent registration	F	Physical interactions controlling folding and solution behavior of biological macromolecules, including proteins, nucleic acids, and membranes.
BC 563	Molecular Genetics	4	LIFE 201B, BC 401	F	Mechanisms of replication, transcription, translation, & packaging of genetic material.
BC 565	Molecular Regulation of Cell Function	4	LIFE 210, BC 403, or concurrent registration in BC 351	S	Molecular regulations of cell organization, membrane formation, organelle biogenesis, cell communication, shape and motility, growth, aging, and death.
BC 665	Adv Topics--Cell Regulation: Microscopic Methods	2	BC 565	F, S	Analysis of cell behavior, function and regulation.
BMS 500	Mammalian Physiology I	4	6 credits of biological science	F	Membrane function and electrical activity of cells, neurophysiology, blood and immune, muscle physiology, and cellular endocrinology.

BMS 501	Mammalian Physiology II	4	6 credits of biological science	S	Cardiovascular, respiratory, renal, digestive, endocrine, metabolic, reproductive function.
BMS 545	Neuroanatomy	3	Written consent of instructor	S	Nervous system structure and function from a systems perspective.
BMS 575	Human Anatomy Dissection	4	BMS 301 and written consent of instructor	F	Human cadaver dissection.
BMS 619	Advanced Human Gross Anatomy	2	Written consent of instructor	F	Clinical application of human anatomy through case study.
CHEM 515	Polymer Chemistry	3	CHEM 346, CHEM 476	F, O	Fundamentals of polymer chemistry: synthesis, characterization, physical properties.
CHEM 545	Synthetic Organic Chemistry I	3	CHEM 543	S	Reactions and synthesis in organic chemistry.
CHEM 549	Synthetic Organic Chemistry II	3	CHEM 545	F	Modern synthetic methods. Strategies for total synthesis of natural products.
ERHS 550	Principles of Radiation Biology	5	ERHS 300 or ERHS 530, BIO 310	S	Dose-response relationships; physical, chemical, and biological modification of radiation damage; radiation oncology; radiation genetics and oncogenesis.
ERHS 712	Physics of Diagnostic Imaging	3	DVM or equivalent professional veterinary medicine degree	F, O	Physics of imaging for radiology, ultrasounds, computerized tomography, magnetic resonance, and nuclear medicine.
ERHS 751	Advanced Radiation Biology I	3	ERHS 550	F, E	Molecular and cellular mechanisms of radiation damage and repair; mammalian radiation genetics.
ERHS 753	Advanced Radiation Biology II	3	ERHS 550	S, O	Perturbations in cell cycle and cell population growth kinetics by radiation; radiation effects on normal tissues; radiation oncogenesis.
HES 531	Muscle and Joint System Mechanics	3	BMS 301; HES 307	F, E	Integrate muscle, tendon, and location of bone attachment into a comprehensive understanding of human movement at the single- and multi-joint level.
HES 619	Advanced Neural control of Movement	3	BMS300, BMS301, BMS 345, BMS500	F, O	Advanced neuroanatomical, neurophysiological, applied aspects of human movement and control of muscle force.
HES 730	Cardiovascular Pathophysiology	3	HES 403, HES 420 or HES 520	F, O	The focus of this course is on cardiovascular physiology with an emphasis on the development, progression, and treatment of diseases of the cardiovascular system.
HES 735	Human Cardiovascular Control	3	HES 403	F, E	Advanced discussion - dynamics of cardio- vascular control in human health/disease.
MIP 530	Advanced Molecular Virology	3	BC 351 or BC 401; MIP 450	S, E	Animal virus structure, replication; viral latency, oncogenicity, and genetics. Comparative virology.
MIP 550	Microbial and Molecular Genetics Laboratory	4	MIP 301 or MIP 302; MIP 450, written consent of instructor	S	Use of both in vivo genetics and in vitro molecular techniques to study gene structure, function, and regulation in bacteria.

MIP 651	Immunobiology	3	MIP 342	F, E	Structure, function, regulation of immunoglobulins and the immune system. Cellular immunity including transplantation and cancer.
NB 502	Techniques in Neuroscience I	2	One college-level course with laboratory in each: biology, biochemistry, physics, and written consent of instructor	F	Current methods in molecular and cellular neurobiology.
NB 503	Developmental Neurobiology	3	One college-level course in each: biology,biochemistry, physics, calculus	S	Molecular mechanisms involved in development of nervous system including differentiation, growth, pathfinding, and synaptogenesis.
NB 505	Neuronal Circuits, Systems and Behavior	3	BMS 325 or BMS 500 or NB 501	S	Anatomical and physiological organization of the nervous system.
NB 750	Physiology of Ion Channels	2	BMS 500; written consent of instructor	S, O	Physiological and structural analysis of membrane ion channels.
VM 640	Biology of Disease I	6		S	Introduction to mechanisms of subcellular, cellular, tissue, and organ response to injury and associated pathological processes.
VS 660	Neurology and Neurosurgery	3		S	Diagnostic and surgical techniques for the nervous system.
VS 681A1	Comparative Pain Medicine II	2	BSPM 500 and BSPM 501 or VM 618 and VM619	S	
Other Electives					
BIOM 784	Supervised College Teaching	1-2		F, S, SS	
BIOM 790	Doctoral Laboratory Rotations	Var.	Written permission of instructor	F, S, SS	
BIOM 795	Independent Study	1-2		F, S, SS	
GRAD 511	High Performance Computing and Visualization	3	GRAD 510 or written consent of instructor	S	Iterative methods for linear systems; Monte Carlo methods; visualization and image processing.
MATH 517	Introduction to Mathematical Analysis I	3	MATH 417	F	Euclidean spaces, metric spaces, sequences, series, limits, continuity, differentiability, Reimann-Stieltjes integral.
MATH 518	Introduction to Mathematical Analysis II	3	MATH 369, MATH 517	S	Sequences and series of functions. Differential and integral calculus of functions of several variables.
MATH 546	Partial Differential Equations II	3	MATH 545	S	Laplace's equation, Green's functions, complex variable methods, eigenfunction expansions.

MATH 652	Finite Element Methods	3	MATH 560	S	Rayleigh-Ritz, Galerkin, and collocation methods, variational inequalities approximations over rectangles and triangles, applications and computing.
MGT 450	Biomedical Entrepreneurship	2	BIOM 470/MECH 470 or MGT 340	F	Commercialization process for biomedical inventions: market and competitor analysis, regulations, patents; preliminary feasibility study.
NB 771	Writing, Submitting, and Reviewing Grants	1		F	Preparation of NRSA fellowship proposals; proposal review; possible submission to NIH for funding.
PHIL 666	Science and Ethics	3		S, O	Ethical issues of research on humans and animals; Biosafety; fraud and deception in science; genetic engineering.
STAT 511	Design and Data Analysis for Researchers I	4	STAT 301 or STAT307/EHCC 307 or STAT 309 or STAT 311 or written consent of instructor.	F	Statistical methods for experimenters and researchers emphasizing design and analysis of experiments.
STAT 540	Data Analysis and Regression	3	Six credits of upper-division statistics courses	F	Introduction to multiple regression and data analysis with emphasis on graphics and computing.
STAT/ERHS 544	Biostatistical Methods for Quantitative Data.	3	EHCC 307/STAT 307 or STAT 301.	S	Regression and analysis of variance methods applied to both observational studies and designed experiments in the biological sciences.
STAT 560	Applied Multivariate Analysis	3	STAT 520, STAT 540	F, S	Multivariate analysis of variance; principal components; factor analysis; discriminant analysis; cluster analysis.
STAT 600	Statistical Computing	3	STAT 520, STAT 540	F, S	Optimization and integration in statistics; Monte Carlo methods; simulation; bootstrapping; density estimation; smoothing.

Courses Recommended to Strengthen Competencies (Not required nor applicable towards degree)

Course Number	Title	Credits	Prerequisite(s)	Semesters Taught	Catalog Description
MATH 151	Mathematical Algorithms in Matlab I	1	MATH 141 or MATH 155 or MATH 160	F, S	Statements, expressions and variable assignments, scripts, control statements and logical statements. Newton's method, Simpson's rule, recursion.
MATH 152	Mathematical Algorithms Maple	1	MATH 141 or MATH 155 or MATH 160	F, S	Iteration and recursion, control and logical statements, expression, functions, data types, binary numbers, symbolic manipulation of terms.