SCHOOL OF BIOMEDICAL ENGINEERING
COLORADO STATE UNIVERSITY

PhD-Bioengineering Curriculum Requirements & Course Information

Curriculum Requirements:

The following lists the specific requirements for the PhD degree. (Students must be able to answer yes to the following statements to earn a PhD 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 research twice. 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 Scott College of Engineering and three credits from the Life Sciences.
- □ Successful completion of the Qualifying Process.
- □ Successful completion of the Preliminary Exam.
- □ Successful completion of the Dissertation Defense.

The 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.

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. However, given the students' varied backgrounds prior to matriculating in the proposed program, it is anticipated that some of these courses will be formally waived.

Course Number	Title	Credits	Prerequisite(s)	Semesters Taught	Catalog Description
3 credits of MATH course(s)	Any 500-level or above MATH course	3 to 4	See course catalog to view prerequisites.	F, S	**See course catalog for detailed descriptions.**
BIOM/CIVE 533*	Biomolecular Tools for Engineers	3	BMS 300 or MIP 300	F	Theoretical and practical aspects of biomolecular laboratory tools--PCR, cloning, sequencing, single-molecule optical techniques and live-cell imaging.
BIOM/MECH 570	Bioengineering	3	MECH 307 and MECH 324	S	Physiological and medical systems analysis using engineering methods including mechanics, fluid dynamics, control electronics, and signal processing.
BIOM/MECH 576	Quantitative Systems Physiology	4	BMS 300 and CHEM 113 and MATH 340 and PH 142	S	Quantitative, model-oriented approach to cellular and systems physiology with design examples from biomedical engineering.
BIOM 592	Seminar	1 x 4 sems.		F, S	Student and research faculty presentations, guest and invited extramural speakers.
BIOM 799	Dissertation	Var.		F, S	
ECE 514**	Applications of Random Processes	3	(ECE 303 or STAT 303 and ECE 312 - with a minimum grade of C)	F	Bit-error rates, signal-to-noise power ration, signal detection, signal estimation, Wiener filter, application.
-OR-					
STAR 513**^ and 531**^	Regression Models and Generalized Regression Models for Researchers	2 per module	See course catalog to view prerequisites.	F, S	**See course catalog for detailed descriptions.**

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

**Students must either take ECE 514 or STAR 513 and STAR 531.

^ Strongly encouraged to take.

Technical Elective Courses

The following represent some of the courses currently available university-wide that could serve as acceptable courses outside of the core requirements. PhD students are strongly recommended to take six credits of engineering electives and three credits of life science electives (500-level or above) at the discretion of the Graduate Affairs Committee. The following course list is meant to illustrate the broad and diverse elective course offerings available to students enrolled.

Engineering Technical Electives (six credits minimum)					
Course Number	Title	Credits	Prerequisite(s)	Semesters Taught	Catalog Description
BIOM/CBE 504	Fundamentals of Biochemical Engineering	3	(MIP 300) and (MATH 255 or MATH 340) and (BIOM 306. may be taken concurrently or BTEC 306, may be taken concurrently or CBE 320, may be taken concurrently).	F	Application of chemical engineering principles to enzyme kinetics, fermentation and cell culture, product purification, and bioprocess design.
BIOM/ECE 517	Advanced Optical Imaging	3	ECE 342 or MATH 340 or MATH 345	F, E	Engineering design principles of advanced optical imaging techniques and image formation theory.
BIOM/ECE 518	Biophotonics	3	ECE 342 or ECE 457 or MATH 340 or MATH 345	F, O	Engineering design principles of optical instrumentation for medical diagnostics. Light propagation and imaging in biological tissues.
BIOM/MECH 525	Cell and Tissue Engineering	3	BC 351 or BMS 300 or BMS 500 or BZ 310 or NB 501	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) and (PH 122 or PH 142)	F, O	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	Selection of structural engineering materials by properties, processing, and economics; materials for biomedical and biotechnology applications.
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/ECE 537	Biomedical Signal Processing	3	MATH 340 or ECE 311 or STAT 303	S	Measuring, manipulating, and interpreting biomedical signals.

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/MECH 574	Bio-Inspired Surfaces	3	CHEM 111 and MECH 342	S	Analysis of surface functionalities of various biological species; identification of design principles.
BIOM/MECH 578	Musculoskeletal Biosolid Mechanics	3	CIVE 360	F	Application of engineering concepts to quantify the mechanical behavior of load-bearing biological tissues and orthopaedic implant performance.
CBE 501	Chemical Engineering Thermodynamics	3	CBE 202 and MATH 340	F	Definition, correlation, and estimation of thermodynamic properties; nonideal chemical and physical equilibria.
CBE 502	Advanced Reactor Design	3	CBE 320 and CBE 322	F	Nonideal flow and tracers, reactions and diffusion, evaluation of complex kinetics, stability of reactors. Biochemical reactor examples.
CBE 570	Biomolecular Engineering/Synthetic Biology	3	(BCE 351) and (CHEM 341 or CHEM 345)	S	Rational design and evolutionary methods for engineering functional protein and nucleic acid systems.
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	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.
CS 514	Software Product and Process Evaluation	4	CS 414	F	Software development process modeling and evaluation; software metrics, testing, verification, validation; experimental methods in software engineering.
CS 517	Software Specification and Design	4	CS 414	S	Rigorous techniques for modeling, specifying, and analyzing software requirements and designs; reusable software development.
ECE 504	Physical Optics	3	ECE 342	F, O	Classical optics from first principles; basic electromagnetic theory to wave and geometric guides.
ECE 506	Optical Interferometry and Laser Metrology	3	ECE 342 and ECE 441	F, O	High resolution metrology techniques utilizing and interferometric sensors using lasers and other light sources.

ECE 514*	Applications of Random Processes	3	(ECE 303 or STAT 303) and ECE 312 with a minimum grade of C for all classes.	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 or MATH 369) and (MATH 317)	S, O	Linear and nonlinear optimization theory and methods; applications in systems, control, and communication.
MECH/ECE 569	Micro-Electro-Mechanical Devices	3	ECE 331 or MECH 344 with grade of C or better for both classes	S	Micro-electro-mechanical processes and applications in sensors, optics, and structures.
ECE 652	Estimation and Filtering Theory	3	ECE 514 or STAT 525	S, O	Linear and Nonlinear parameter and state estimation methods; Optimal Kalman state estimation and applications.
MECH 502	Advanced/Additive Manufacturing Engineering	3	MECH 202 and MECH 331	S	Materials, controls, and mechanics applied to additive manufacturing; rapid prototyping; direct digital manufacturing.
MECH 524	Principles of Dynamics	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 and 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 plan to take as core course.*

Life Science Technical Electives (not required but recommended)

Course Number	Title	Credits	Prerequisite(s)	Semesters Taught	Catalog Description
BC 512	Principles of Macromolecular Structure	1	BC 411 – may be 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 and BC 401	F	Mechanisms of replication, transcription, translation, & packaging of genetic material, emphasizing original literature and methods.
BC 565	Molecular Regulation of Cell Function	4	LIFE 210 and (BC 403 or BC 351 – may be taken concurrently)	S	Molecular regulations of cell organization, membrane formation, organelle biogenesis, cell communication, shape and motility, growth, aging, and death.

BC 665A	Adv Topics--Cell Regulation: Microscopic Methods	2	BC 565	F, S	Analysis of cell behavior, function and regulation.
BMS 500	Mammalian Physiology I	4	BMS 300 or BMS 360	F	Cell physiology of nerve, skeletal, cardiac and smooth muscle with an emphasis on how cellular functions integrate into systems behavior.
BMS 501	Mammalian Physiology II	4	BMS 300 or BMS 360	S	Respiratory, renal, digestive, endocrine, metabolic, and reproductive function.
BMS 545	Neuroanatomy	5		S	Nervous system structure and function presented from a systems perspective; applied and comparative aspects are emphasized.
BMS 575	Human Anatomy Dissection	4		F	Regional approach to human gross anatomy through dissection of human cadaver.
BMS 619	Advanced Human Gross Anatomy	2		F	Clinical application of human anatomy through case study.
CHEM 515	Polymer Chemistry	3	CHEM 346 and CHEM 476	F, O	Fundamentals of polymer chemistry: synthesis, characterization, physical properties.
CHEM 533	Chemical Separations	3	CHEM 335 and CHEM 431	S, E	Fundamentals and applications of chemical separations.
CHEM 545	Synthetic Organic Chemistry I	3	CHEM 543	S	Reactions and synthesis in organic chemistry.
CHEM 549	Synthetic Organic Chemistry II	2	CHEM 545	S	Strategies for total synthesis of natural products.
ERHS 550	Principles of Radiation Biology	5	(BZ 310) and (ERHS 450 or ERHS 530)	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		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.
MIP 530	Advanced Molecular Virology	4	(BC 351 or BC 401) and (MIP 450 or BC 463)	S, E	Virus-host interactions at the molecular and cellular level.
MIP 550	Microbial and Molecular Genetics Laboratory	4	MIP 302 and MIP 450	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	Structure, function, regulation of immunoglobulins and the immune system. Cellular immunity including transplantation and cancer.

CM/NB 502	Techniques in Molecular and Cellular Biology	2	(BIO 100 to 481 - at least 4 credits or BZ 100 to 481 - at least 4 credits or LIFE 100 to 481 - at least 4 credits) and (BC 100 to 481 - at least 4 credits and PH 100 to 481 - at least 4 credits)	F	Current methods in molecular and cellular neurobiology.
NB 503	Developmental Neurobiology	3	(BIO 100 to 481 - at least 1 course or BZ 100 to 481 - at least 1 course or LIFE 100 to 481 - at least 1 course) and (BC 100 to 481 - at least 1 course and PH 100 to 481 - at least 1 course) and (MATH 141 or MATH 155 or MATH 160 to 161 - at least 1 course or MATH 255 or MATH 261)	S	Molecular mechanisms involved in development of nervous system including differentiation, growth, pathfinding, and synaptogenesis.
BMS/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	S, O	Physiological and structural analysis of membrane ion channels.
VS 660	Neurology and Neurosurgery	3		S, (every third year)	Diagnostic and surgical techniques for the nervous system.
Other Technical Electives					
Course Number	**Title**	**Credits**	**Prerequisite(s)**	**Semesters Taught**	**Catalog Description**
BIOM 784	Supervised College Teaching	Var. (1-6)		F, S, SS	
BIOM 795	Independent Study	Var. (1-6)		F, S, SS	

GRAD 511	High Performance Computing and Visualization	3	GRAD 510	F	Iterative methods for linear systems; Monte Carlo methods; visualization and image processing.
MATH 517	Introduction to Real Analysis	3	MATH 417 and MATH 369	F	Euclidean and metric spaces, compactness, continuity, sequences, series, multivariable differentiation, inverse and implicit function theorems.
MATH 546	Partial Differential Equations II	3	MATH 545	S	Distribution theory, Green;s functions, sobolev spaces, elliptic and parabolic equations.
MATH 652	Advanced Numerical Methods for PDEs	3	MATH 560 or MATH 545 or MATH 617	F	Theory of numerical methods for solution of PDEs: convergence and stability properties; error estimation; approximation theory.
MGT 450	Biomedical Entrepreneurship	2	BIOM 470 or MECH 470 or MGT 340	S	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.
STAR 511	Design and Data Analysis for Researchers I: R Software	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 using R software
STAT 540	Data Analysis and Regression	3	STAT 300 to 481 – at least six credits	F	Introduction to multiple regression and data analysis with emphasis on graphics and computing,
STAT/ERHS 544	Biostatistical Methods for Quantitative Data	3	ERHS 307 or 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 and STAT 540	F, S	Multivariate analysis of variance; principal components; factor analysis; discriminant analysis; cluster analysis.
STAT 600	Statistical Computing	3	STAT 520 and 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)	Sem. Taught	Catalog Description
MATH 151	Mathematical Algorithms in Matlab I	1	MATH 141 or MATH 155 or MATH 160	S	Statements, expressions and variable assignments, scripts, control statements and logical statements. Newton's method, Simpson's rule, recursion.
MATH 152	Mathematical Algorithms in Maple	1	MATH 141 or MATH 155 or MATH 160	S	Iteration and recursion, control and logical statements, expression, functions, data types, binary numbers, symbolic manipulation of terms.