



Biomedical Engineering Graduate Concentrations

Bioelectrics and Neural Engineering: Bioelectricity is the study of electrical fields and potentials within the body. In the bioelectrical concentration students learn how to examine and control these fields towards developing medical devices and restorative therapies. The core classes within this concentration focus on 1) examining nerve and cardiac bioelectrical fields from a computational standpoint and 2) understanding techniques to model neurons and to stimulate and record from individual and large populations of neurons. Electives within this concentration include courses on medical imaging, systems-level neuroscience, and introductions to microelectronics and signal processing. Students graduating from BME with a bioelectrical concentration will be able to work as engineers in the rapidly expanding fields of neural engineering, medical diagnostics, and medical systems industries, or pursue advanced degrees in medicine, basic medical sciences, or bioelectrical engineering.

Advisor: Prof. Tim Bruns

Biomaterials and Regenerative Medicine: Biomaterials is the study of interactions between living and non-living materials. Students trained in biomaterials must have a thorough understanding of the materials they work with and properties of the biological system they seek to replace or regenerate. Biomaterials are also an integral component in tissue engineering and regenerative medicine. Biomaterials research areas include: design of orthopaedic, dental, cardiovascular and neuro-sensory prostheses, artificial organs, blood-surface interactions, cellular and tissue engineering, drug delivery, biosensors, microencapsulation technology, and implant retrieval analysis. Students graduating from BME with a concentration in biomaterials will be capable of working in the medical device, tissue engineering or pharmaceutical industries, academic or government laboratories, or pursuing further education in Ph.D. or professional programs. *Advisor: Prof. David Kohn*

Biomechanics and Biotransport: Biomechanics is a hybrid discipline requiring a thorough understanding of classic engineering mechanics, physiology and cell biology, and the interface between the two. Biomechanics also has important applications in cutting-edge fields like tissue engineering and mechanotransduction. In tissue engineering, one tries to regenerate new tissues to replace defects in existing tissue. This requires knowledge of tissue-mechanical function. Mechanotransduction is the study of how cells sense and react to mechanical stimulus, a field with applications in such diverse areas as hearing (haircell movement in fluids) and orthopaedics (bone and tendon response to physical stress). Graduates in this concentration will be prepared for a wide range of industries concerned with mechanical effects on the human body including surgical device industries, automotive safety, and biotech industries concerned with mechanically functional tissue. Students will also have excellent preparation to attend medical school or pursue a Ph.D. *Advisor: Prof. David Kohn*

Biomedical Imaging and Ultrasonics: Since the invention of x-ray computerized tomography more than 25 years ago, imaging has become the primary noninvasive diagnostic tool available to the clinician. Although many principles are common to all imaging modalities, biomedical imaging scientists and engineers must understand the basic physics and operating principles of all primary modalities including magnetic resonance imaging (MRI), radiography and nuclear medicine, optics, and ultrasound. Major biomedical imaging companies require such multi-modality expertise to design new devices and procedures. In addition, clinical problems increasingly require the techniques of cell and molecular biology to design both new contrast agents and imaging methods for a wider range of applications. The biomedical imaging curriculum recognizes trends and requires students to have a solid background in signal processing and imaging science, and simultaneously be literate in both the basic life sciences and the basic operating principles of several imaging modalities. Graduates of this program will be well prepared to work in the medical imaging industry, to attend medical school, or to study for a Ph.D. in BME. *Advisor: Prof. Xueding Wang*

Biotechnology and Systems Biology: Advances in cellular and molecular biology have changed and expanded the ways therapeutic devices and drugs are designed. Modern biotechnology depends on scientists and engineers who study the fundamental properties of cell, molecular, and tissue biology, and apply these to engineer materials and technology to interact with living systems. Goals include production of improved biomaterials for medical

implants and prosthetics, tissues engineered for specific functionality, and new therapeutic drugs. The biotechnology curriculum emphasizes critical areas of chemistry, molecular biology, and cell biology, but also exposes students to a broad range of engineering approaches necessary for this interdisciplinary field. Graduates of this program will be well prepared for jobs in the pharmaceutical or medical device industries, to attend professional schools, or to study for a Ph.D. *Advisor: Prof. Deepak Nagrath*

Medical Product Development: The design and development of medical devices and systems is unique in the way they are regulated and structured. Biomedical engineers can play key roles at all stages of medical product development, from needs finding and concept generation to design, prototyping, testing, fabrication, and commercialization. The goal of this concentration is to provide students with the practical knowledge and skills needed to bring new and improved devices to the clinic, in the context of the current healthcare environment. The core course is a two-semester design-build-test experience in which student teams work to solve real clinical problems in collaboration with practicing physicians. This experience is augmented with elective courses in regulatory affairs, quality systems, intellectual property, innovation, and other topics relevant to the development and commercialization of medical products. Graduates of this program will be well prepared for jobs in product development in a variety of medically-oriented industries, including biotechnology, pharmaceuticals, and medical devices. *Advisor: Prof. Jan Stegemann*

SCHEMATIC OF COMPONENTS OF THE MASTERS COURSE CURRICULUM:

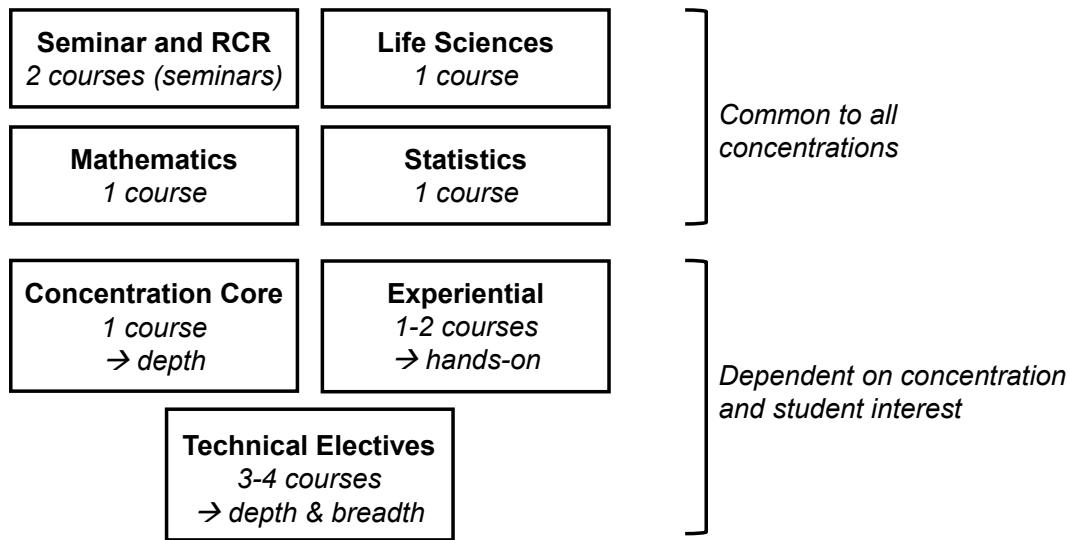


Fig. 1: General components of Masters curriculum in Biomedical Engineering.

CONCENTRATION CORE:

Bioelectrics and Neural Engineering (at least one course):

- BIOMEDE 417 Electrical Biophysics (4) (I)
- BIOMEDE 517 Neural Engineering (3) (II)

NOTE: Students who have previously taken an undergraduate bioelectricity course are advised to take BIOMEDE 517 instead of BIOMEDE 417.



Biomaterials and Regenerative Medicine:

BIOMEDE 410 Design and Applications of Biomaterials (3) (I)

Biomedical Imaging and Ultrasonics:

BIOMEDE 516 Medical Imaging Systems (3) (I)

Biomechanics and Biotransport (at least one course):

BIOMEDE 456 Tissue Mechanics (3) (I)

BIOMEDE 476 Biofluid Mechanics (4) (II)

Biotechnology and Systems Biology (at least one course):

BIOMEDE 504 Cellular Biotechnology (3) (II)

BIOMEDE 584 Advances in Tissue Engineering (3) (II, even years)

BIOPHYS 440 Biophysics of Diseases (3) (I)

CHE 517 Biochemical Engineering (3) (I)

Medical Product Development (both courses are required):

NOTE: These courses satisfy both the Concentration Core and the Experiential Component in the Medical Product Development concentration.

BIOMEDE 599.002 Graduate Innovative Design in Biomedical Engineering Pt. 1 (3) (I)

BIOMEDE 599.004 Graduate Innovative Design in Biomedical Engineering Pt. 2 (4) (II)

EXPERIENTIAL COMPONENT (at least one course):

BIOMEDE 458 ¹ Biomedical Instrumentation and Design (4) (I,II)

BIOLCHEM 516 Introductory Biochemistry Laboratory (3) (I,II)

BIOMEDE 510 Medical Imaging Laboratory (3) (II)

IOE 432 Industrial Engineering Instrumentation Methods (3) (I)

MCDB 429 Laboratory in Cell and Molecular Biology (3) (II)

BIOMEDE 590 ² Directed Research (2-6) (I,II,III,IIIa,IIIb)

BIOMEDE 599.002/004 ³ Graduate Innovative Design in Biomedical Engineering (3/4, I/II)

NOTES: ¹ Required for students without prior, approved bioinstrumentation course. Students with prior bioinstrumentation course can take an additional bioinstrumentation course from this list. Students in the Biomedical Imaging and Ultrasonics concentration may take BIOMEDE 510 in place of BIOMEDE 458. SUGS students who took BIOMEDE 458 as undergraduates and counted it toward their BS degree must take an additional course to satisfy the experiential component of the MS degree.

² Students can count up to 6 letter-graded credits of BIOMEDE 590 toward the MS degree. Students who count 4 or more credits, either in a single or multiple terms, are required to complete a MS Thesis and defense. PhD students can also count the MS Thesis and defense as the BME Qualifying Examination.

³ Priority given to students in Medical Product Development concentration. This is a full-year course; both Fall and Winter sessions must be taken.



SEMINAR AND RESPONSIBLE CONDUCT OF RESEARCH (both courses are required):

| | |
|-------------|-------------------------------------------|
| BIOMEDE 500 | Biomedical Engineering Seminar (1) (I,II) |
| BIOMEDE 550 | Ethics and Enterprise (1) (I) |

NOTES: Recommended to be taken in first term or year of study.
BIOMEDE 550 satisfies UM Responsible Conduct of Research and Scholarship (RCRS) requirement.

MATHEMATICS (choose one course):

Courses recommended for BME students:

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|----------|----------------------------------------------------------------------------|
| MATH 450 | Advanced Mathematics for Engineers I (4) (I,II) |
| MATH 454 | Boundary Value Problems for Partial Differential Equations (3) (I,II,IIIa) |
| MATH 463 | Mathematical Modeling in Biology (3) (I) |

Other courses with specialized content:

| | |
|-------------|------------------------------------------------------------------------------|
| MATH 462 | Mathematical Models (3) (II) |
| MATH 471 | Introduction to Numerical Methods (3) (I,II,IIIb) |
| MATH 540 | Mathematics of Biological Networks (3) (I) |
| MATH 550 | Introduction to Adaptive Systems (3) (I) |
| MATH 555 | Introduction to Functions of a Complex Variable with Applications (3) (I,II) |
| MATH 556 | Applied Functional Analysis (3) (I) |
| MATH 557 | Applied Asymptotic Analysis (3) (II) |
| MATH 558 | Applied Nonlinear Dynamics (3) (I) |
| MATH 559 | Topics in Applied Mathematics (3) (varies) |
| MATH 561 | Linear Programming I (3) (I,II) |
| MATH 562 | Continuous Optimization Methods (3) (II) |
| MATH 563 | Advanced Mathematical Methods for the Biological Sciences (3) (II) |
| MATH 564 | Topics in Mathematical Biology (3) (II) |
| MATH 571 | Numerical Linear Algebra (3) (I,II) |
| MATH 572 | Numerical Methods for Differential Equations (3) (II) |
| MATH 651 | Topics in Applied Mathematics I (3) (II) |
| MATH 656 | Introduction to Partial and Differential Equations (3) (I) |
| MATH 657 | Nonlinear Partial Differential Equations (3) (II) |
| MATH 756 | Advanced Topics in Partial Differential Equations (3) (II) |
| MECHENG 501 | Mathematical Methods in Mechanical Engineering (3) (I) |
| MECHENG 564 | Linear Systems Theory (4) (I,II) |

STATISTICS (choose one course):

Course recommended for BME students:

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|-------------|---------------------------------------------------------|
| BIOMEDE 503 | Statistical Methods for Biomedical Engineering (3) (II) |
|-------------|---------------------------------------------------------|

Other courses with specialized content:

| | |
|-------------|------------------------------------------------------------------|
| BIOSTAT 602 | Biostatistical Inference (4) (II) |
| BIOSTAT 650 | Applied Statistics I: Linear Regression (4) (I) |
| BIOSTAT 651 | Applied Statistics II: Extensions for Linear Regression (3) (II) |
| EECS 501 | Probability and Random Processes (4) (I,II) |
| IOE 461 | Quality Engineering Principles and Analysis (3) (I) |



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|-----------|---------------------------------------------------|
| STATS 470 | Introduction to the Design of Experiments (4) (I) |
| STATS 500 | Statistical Learning I: Regression (3) (I) |
| STATS 525 | Probability Theory (3) (I) |

NOTE: BME graduate students can only take EECS 501 in the winter term.

LIFE SCIENCES (choose one course):

Courses recommended for BME students:

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|--------------|--------------------------------------|
| BIOMEDE 519 | Quantitative Physiology (4) (I) |
| BIOLCHEM 515 | Introductory Biochemistry (3) (I,II) |
| CDB 530 | Cell Biology (3) (I) |
| CDB 550 | Histology (4) (II) |

Other courses with specialized content:

| | |
|--------------|----------------------------------------------------------------------------|
| ANATOMY 403 | Human Anatomy: Structure and Function (5) (I,II) |
| ANATOMY 541 | Mammalian Reproductive Physiology (4) (II) |
| BIOLCHEM 451 | Advanced Biochemistry: Macromolecular Structure and Function (4) (I) |
| BIOPHYS 520 | Methods of Biophysical Chemistry (3) (I) |
| CANCBIO 553 | Molecular Biology of Cancer (3) (I) |
| CANCBIO 554 | Cancer Pathogenesis and Treatment (3) (II) |
| CDB 581 | Development Genetics (3) (I) |
| CDB 583 | Organogenesis: Stem Cells to Regenerative Biology (3) (II) |
| KINESLGY 522 | Clinical Neurophysiology and Neuroimaging (3) (varies) |
| KINESLGY 545 | Metabolic Responses to Exercise (3) (II) |
| MCDB 422 | Brain Development, Plasticity, and Circuits (3) (II) |
| MCDB 423 | Introduction to Research in Cellular and Molecular Neurobiology (3) (I,II) |
| MCDB 427 | Molecular Biology (4) (I,II) |
| MCDB 428 | Cell Biology (4) (I,II) |
| MCDB 435 | Intracellular Trafficking (3) (II) |
| MICRBIOL 440 | Human Immunology (3) (II) |
| NEUROSCI 570 | Human Neuroanatomy I (3) (I) |
| NEUROSCI 601 | Principles of Neuroscience I (3) (I) |
| NEUROSCI 602 | Principles of Neuroscience II (3) (II) |
| PATH 581 | Tissue, Cellular and Molecular Disease (3) (II) |
| PHYSIOL 592 | Integrated Neuroscience (2-4) (II) |

TECHNICAL ELECTIVES:

Students must take sufficient technical elective credits to reach at least the 30 credits overall required for the MS degree.

NOTE: Students in any concentration may take one technical elective from the Medical Product Development list of technical electives (see Page 8).

Bioelectrics and Neural Engineering

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|-------------|------------------------------------------|
| BIOMEDE 510 | Medical Imaging Laboratory (3) (II) |
| BIOMEDE 516 | Medical Imaging Systems (3) (I) |
| BIOMEDE 517 | ¹ Neural Engineering (3) (II) |



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|-----------------|--------------------------------------------------------------|
| BIOMEDE 599.010 | Current Topics in Neuromodulation (3) (II) |
| EECS 414 | Introduction to MEMS (4) (I) |
| EECS 425 | Integrated Microsystems Laboratory (4) (II) |
| EECS 427 | ² VLSI Design I (4) (I,II) |
| EECS 445 | ² Intro Machine Learning (4) (I,II) |
| EECS 522 | ² Analog Integrated Circuits (4) (II) |
| EECS 545 | ^{2,3} Machine Learning (3) (I,II) |
| EECS 564 | ^{2,3} Estimation, Filtering, and Detection (3) (II) |
| NEUROSCI 613 | Circuits and Computational Neuroscience (1) (I) |
| NEUROSCI 614 | Sensory and Systems Neuroscience (1) (II) |
| NEUROSCI 615 | Cognitive and Behavioral Neuroscience (1) (II) |

NOTES: ¹ Can be taken as an elective if BIOMEDE 417 is taken as the concentration core.
² EECS courses are challenging without an appropriate background. Students are recommended to verify prerequisites and contact course instructors prior to registration.
³ Must take EECS 501 prerequisite, which also covers the STATISTICS component.

Biomaterials and Regenerative Medicine

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|-----------------|-------------------------------------------------------------------------|
| BIOMEDE 418 | Quantitative Cell Biology (3) (I,II) |
| BIOMEDE 456 | Tissue Mechanics (3) (I) |
| BIOMEDE 476 | Biofluid Mechanics (4) (II) |
| BIOMEDE 479 | Biotransport (4) (II) |
| BIOMEDE 563 | Biomolecular Engineering of Interfaces (3) (II) |
| BIOMEDE 584 | Advances in Tissue Engineering (3) (II, even years) |
| BIOMEDE 599.011 | Engineering Approaches to Cancer Biology (3) (II) |
| | |
| MATSCIE 412 | Polymeric Materials (3) (I) |
| MATSCIE 420 | Mechanical Behavior of Materials (3) (I) |
| MATSCIE 440 | Ceramic Materials (3) (II) |
| MATSCIE 465 | Structural and Chemical Characterization of Materials (3) (I,II) |
| MATSCIE 512 | Physical Polymers (3) (II) |
| MATSCIE 514 | Composite Materials (3) (II) |
| MATSCIE 515 | Mechanical Behavior of Solid Polymeric Materials (3) (II) |
| MATSCIE 517 | Advanced Functional Polymers: Molecular Design and Applications (3) (I) |
| MATSCIE 560 | Structure of Materials (3) (I) |
| MATSCIE 562 | Electron Microscopy I (4) (II) |
| MATSCIE 577 | Failure Analysis of Materials (3) (I,II) |

Biomedical Imaging and Ultrasonics

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|-------------|------------------------------------------------------------|
| BIOMEDE 510 | Medical Imaging Laboratory (3) (II) (Strongly recommended) |
| BIOMEDE 417 | Electrical Biophysics (4) (I) |
| BIOMEDE 418 | Quantitative Cell Biology (4) (I,II) |
| | |
| EECS 556 | Image Processing (3) (II) |

Biomechanics and Biotransport

Technical electives with fluid mechanics content:

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|-------------|-----------------------|
| BIOMEDE 479 | Biotransport (4) (II) |
|-------------|-----------------------|



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|-------------|-------------------------------------------------|
| AEROSP 521 | Experimental Methods in Fluid Mechanics (3) (I) |
| CHE 527 | Fluid Flow (3) (1) |
| CHE 542 | Intermediate Transport Phenomena (3) (II) |
| MECHENG 520 | Advanced Fluid Mechanics I (3) (I) |
| MECHENG 523 | Computational Fluid Dynamics I (3) (I) |
| MECHENG 524 | Advanced Engineering Acoustics (3) (I) |
| MECHENG 530 | Advanced Heat Transfer (3) (I) |
| MECHENG 617 | Mechanics of Polymers II (3) (II) |

Technical electives with biomechanics content:

| | |
|-----------------|------------------------------------|
| BIOMEDE 534 | Occupational Biomechanics (3) (II) |
| MECHENG 599.002 | Cellular Engineering (3) (II) |

Technical Electives with Connective Tissue Content:

| | |
|-------------|------------------------------------------------------------------------------|
| BIOMEDE 410 | Design and Applications of Biomaterials (3) (I) |
| MECHENG 505 | Finite Element Methods in Mechanical Engineering & Applied Mechanics (3) (I) |
| MECHENG 511 | Solid Continua (3) (I) |
| MECHENG 512 | Theory of Elasticity (3) (II) |
| MECHENG 517 | Mechanics of Polymers I (3) (II) |

Technical Electives with Dynamics/Control Content:

| | |
|-------------|------------------------------------------------|
| EECS 562 | Nonlinear Systems & Control (3) (II) |
| MECHENG 440 | Intermediate Dynamics & Vibrations (4) (II) |
| MECHENG 540 | Intermediate Dynamics (4) (I) |
| MECHENG 543 | Analytical & Computational Dynamics I (3) (II) |
| MECHENG 560 | Modeling Dynamic Systems (3) (I) |
| MECHENG 561 | Design of Digital Control Systems (3) (II) |

Biotechnology and Systems Biology

| | |
|-----------------|------------------------------------------------------------------|
| BIOMEDE 410 | Design and Applications of Biomaterials (3) (I) |
| BIOMEDE 456 | Tissue Mechanics (3) (I) |
| BIOMEDE 476 | Biofluid Mechanics (4) (II) |
| BIOMEDE 479 | Bitransport (4) (II) |
| BIOMEDE 504 | Cellular Biotechnology (3) (II) |
| BIOMEDE 599.011 | Engineering Approaches to Cancer Biology (3) (II) |
| BIOINF 527 | Introduction to Bioinformatics and Computational Biology (4) (I) |
| BIOLCHEM 550 | Macromolecular Structure and Function (3) (I) |
| CANCBIO 553 | Molecular Biology of Cancer (3) (I) |
| CDB 550 | Histology (4) (II) |
| CHE 519 | Pharmaceutical Engineering (3) (II) |
| CHE 528 | Reactor Engineering (3) (II) |
| CHE 538 | Statistical and Irreversible Thermodynamics (3) (I) |
| CHE 542 | Intermediate Transport Phenomena (3) (II) |
| CHE 696 | Selected Topics (3) (I,II) |
| EECS 414 | Introduction to MEMS (4) (I) |
| MCDB 611 | Neurochemistry/Neuropharmacology (1) (I) |
| MECHENG 553 | Microelectromechanical Systems (3) (I) |



MECHENG 599.002 Cellular Engineering (3) (II)

Medical Product Development

NOTE: Students in any concentration may take one class from the following list as a technical elective.

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|-----------------|-----------------------------------------------------------------|
| BIOMEDE 499.002 | Clinical Observation and Needs Finding (2) (I) |
| BIOMEDE 504 | Cellular Biotechnology (3) (II) |
| BIOMEDE 523 | Business of Biology (2.25) (I) |
| BIOMEDE 588 | Global Quality Systems and Regulatory Innovation (2) (II) |
| BIOMEDE 599.005 | Instructional Innovation Incubator (3) (I) |
| BE 608 | Health Care Markets and Public Policies (1.5) (I) |
| BIOINF 622 | Translational Research (2) (I) |
| CHE 517 | Biochemical Engineering (3) (I) |
| ENTR 540 | Business Math for Innovators (1.5) (II) |
| ENTR 599.008 | IP Strategy (3) (I) |
| ENTR 599.011 | Technology-Inspired Business Models (3) (I) |
| ENTR 599.014 | An Introduction to Innovation: Tools for Career Success (2) (I) |
| ENTR 599.018 | Interpersonal Skills: Leveling Up to Leadership (3) (I) |
| ENTR 599.020 | Project Management and Consulting (3) (I) |
| ES 512 | Business Basics for Graduate Engineers (3) (II) |
| ES 720 | Commercialization of Biomedicine (1.5) (II) |
| MECHENG 599.003 | Design for Global Health (3) (II) |

KEY AND ADDITIONAL NOTES:

Course Department & Number Course Name (# of credits) (term offered)

Terms: I - fall, II - winter, III - spring-summer, IIIa - spring half, IIIb - summer half

Students are responsible for checking the Registrar's Schedule of Classes to ensure that their selected courses are offered and fit their schedule.

Courses with 499/599 designation are in pilot phase and may not be offered in the term indicated.