Biomedical engineering is a dynamic field stressing the application of engineering techniques and mathematical analysis to biomedical problems. Faculty research programs are key to the program, and they include five primary research directions: rehabilitation engineering, biomedical imaging, pharmacoengineering, regenerative medicine, and biomedical microdevices. The department offers graduate education in biomedical engineering leading to the master of science and doctor of philosophy degrees. Also, a joint graduate certificate in medical devices is offered.

Students enter this program with backgrounds in engineering, physical science, mathematics, or biological science. Curricula are tailored to fit the needs and develop the potential of individual students. In addition, courses in statistics, mathematics, life sciences, and engineering sciences provide a well-rounded background of knowledge and skills.

The Joint Biomedical Engineering Graduate Program is administered by the combined biomedical engineering graduate faculty from both North Carolina State University and the University of North Carolina at Chapel Hill. The joint program also has close working relations with the Research Triangle Institute and industries in the Research Triangle area. These associations enable students to obtain research training in a variety of fields and facilitate the selection and performance of dissertation research. Students in the joint program may study under faculty members based at the University of North Carolina at Chapel Hill or at North Carolina State University. Thus, the department provides students with excellent opportunities to realize the goal of enhancing medical care through the application of modern technology.

Admission Requirements
Students must satisfy all entrance requirements for The Graduate School of the University of North Carolina at Chapel Hill or the Graduate School at North Carolina State University and must demonstrate interest and capability commensurate with the quality of the biomedical engineering program. Prospective students may apply to the graduate school at either UNC–Chapel Hill or North Carolina State University. All applicants are considered together as a group. Generally, applications should be submitted by mid-December for consideration for admission in the coming fall semester. Applicants are expected to present Graduate Record Examination (GRE) scores; verbal scores should be at or above the 50th percentile, and quantitative scores should be at or above the 70th percentile. Applicants are expected to have at least a 30th percentile score on the written GRE component to be competitive. The program requires applicants to submit a one- to three-page personal statement about their research interest and background.

Students should have a good working knowledge of mathematics at least through differential equations, as well as two years of physical or engineering science and basic courses in biological science. Deficiencies in preparation can be made up in the first year of graduate training.

Candidates for the UNC–Chapel Hill/North Carolina State University jointly issued degrees in biomedical engineering must have met the general requirements of The Graduate School of the University of North Carolina at Chapel Hill or the North Carolina State University Graduate School.

Master's students are required to take a comprehensive examination encompassing coursework and thesis research. The master's comprehensive exam may be either written or oral and is administered by the student's advisory committee.

Doctoral students qualify for the Ph.D. degree by meeting grade requirements in their core courses and then advancing to written and oral preliminary exams before admission to candidacy. Details can be found on the department's Web site. Degree candidates in this program are expected to obtain experience working in a research laboratory during their residence and to demonstrate proficiency in research. The Ph.D. dissertation should be judged by the graduate committee to be of publishable quality.

Professors
Nancy L. Allbritton, Signaling in Single Cells, Microfabricated Systems for Cellular Analysis
Paul Dayton, Biomedical Imaging, Medical Imaging, Medical Devices, Medical Instrumentation
Greg Forest, Transport Processes in the Lung, Flow and Structure of Nanomaterials and Macromolecular Fluids
Edward Grant, Robotics, Biomedical Systems, Neural Networks, Biomedical Sensors, Medical Devices
Leaf Huang, Pharmacoengineering
Michael Jay, Pharmacoengineering
Frances Ligler, Microfluidics, Tissue on Chip, Biosensors, Nanotechnology, Optical Analytical Devices
Weili Lin, Medical Imaging, MRI, Cerebral Hemodynamics, Oxygen Metabolism
Terry Magnuson, Genomics, Genetics, Chromatin, Epigenetics, Development and Cancer
Russell Mumper, Pharmacoengineering
Troy Nagle, Medical Devices, Microsensors, Electronic Olfaction
Roger Narayan, Biomedical Sensors, Medical Devices, Biomaterials, Nanometer Systems
Harold Pillsbury, Neurobiology, Cochlear Implants
J. Michael Ramsey, Microfabricated Chemical Instrumentation, Microfluidics, Nanofluidics
Steven Soper, Biomedical Microsystems

Associate Professors
Ted Bateman, Rehabilitation Engineering
Ke Cheng, Stem Cells, Regenerative Medicine
Robert Dennis, Medical Devices, Biomechatronic Design, Tissue Mechanics, Functional Tissue Engineering, Regenerative Medicine
Caterina Gallippi, Biomedical Imaging, Medical Imaging, Image Processing and Analysis
Michael Gamcsik, Biomedical Imaging, Functional Tissue Engineering, Metabolomics, Pharmacy Shawn Gomez, Computational Biology, Bioinformatics, Mathematical Modeling, Genomics, Image Analysis, Systems Biology
Shawn Gomez, Computational Biology, Bioinformatics, Image Analysis, Mathematical Modeling, Systems Biology
He (Helen) Huang, Neural-Machine Interface, Prosthetics and Orthotics, Control of Wearable Robotics
Derek Kamper, Rehabilitation Engineering
David Lalush, Image Analysis, Biomedical Imaging, Medical Imaging, Bioinformatics, Image Processing and Analysis
Jeffrey Macdonald, Metabolomics, Functional Tissue Engineering
Scott Magness, Stem Cell Biology, Niche Dynamics, Tissue Engineering, Biomimetic Scaffolds, Single-Cell Biology
Mark Tommerdahl, Neurobiology, Image Processing and Analysis, Physiological Systems, Somatosensory Cortical Dynamic
Glenn Walker, BioMicroelectromechanical Systems, Microfluidics, Lab-on-a-Chip Systems Research
David Zaharoff, Vaccine and Immunotherapy Delivery Platforms

Associate Research Professors
Oleg Favorov, Digital/Multidimensional Signal Processing, Biomedical Systems, Neural Networks, Bioinformatics, Neurobiology
Richard Goldberg, Medical Instrumentation
Anka N. Veleva, Biomaterials, Biochemical Engineering
Paul Weinhold, Orthopaedic Biomechanics, Vibration Testing of Orthopaedic Tissues and Constructs Teaching

Associate Professors
Lianne Cartee, Mathematical Modeling, Bioelectric Stimulation
Hatice O. Ozturk, Digital Signal Processing/Multidimensional Signal Processing, Biomedical Image Processing and Analysis

Assistant Professors
Ashley Brown, Regenerative Medicine, Biomaterials, Wound Healing, Hemostasis, Microgels
Yevgeny Brudno, Pharmacoeengineering, Regenerative Medicine
Jacqueline Cole, Bone Mechanics, Bone-Vascular Interactions, Aging, Fracture Healing, Stroke Rehabilitation
Michael Daniele, Biosensors, Biomaterials, Bioelectronics, Microfluidics, Materials Chemistry
Matthew Fisher, Regenerative Medicine, Tissue Engineering, Orthopaedic Soft Tissues, Bioscaffolds, Robotics
Jason Franz, Neuromuscular Biomechanics, Sensorimotor Control, Aging and Age-related Mobility Impairment
Donald Freytes, Bioengineered Tissues, Pluripotent Stem Cells, Tissue-Specific Extracellular Matrix Scaffolds
Zhen Gu, Pharmacoeengineering, Controlled Drug Delivery, Bio-Inspired Materials, Protein Engineering, Nanobiotechnology
Xiaogang Hu, Rehabilitation Engineering
Gianmarco Pinton, Biomedical Imaging, Nonlinear Ultrasound Imaging, Simulation
Gregory Sawicki, Bio-inspired Wearable Robotics, Locomotion Physiology, Neural Control of Movement, Rehabilitation Engineering
Michael Sano, Electromagnetics and Biophysics, Microfabrication and Microfluidic Device Development, Cancer Therapies
Anne Marion Taylor, Micro-Scale Devices, Microfluidics, Synapse Formation, Synaptic Plasticity, Protein Synthesis Research

Assistant Professor of the Practice
Andrew DiMeo, Medical Device Development

Lecturers
Kenneth Donnelly
Devin Hubbard
Naji Hussein

BMME

Advanced Undergraduate and Graduate-level Courses
BMME 405. Biomechanics of Movement. 3 Credits.
This course provides an overview of musculoskeletal anatomy, and of the mechanical behavior of biological tissues and biological systems. Students learn to apply fundamental principles of mechanics to analyze movement in humans and other animals. Applications in rehabilitation and orthopedics are emphasized.
Requisites: Prerequisites, BMME 160 and MATH 383.
Grading status: Letter grade.

BMME 410. Systems and Signals. 3 Credits.
Analysis of linear systems by transform methods to networks, including Fourier transforms, Laplace transforms, and convolution. Survey of linear systems applications to biomedical problems.
Requisites: Prerequisite, MATH 383; co-requisite, MATH 528.
Grading status: Letter grade.

BMME 420. Introduction to Synthetic Biology. 3 Credits.
This course provides an introduction to the ideas and methodologies in the field of synthetic biology. Lectures focus on fundamental concepts in molecular biology and engineering as applied to biological system design. The laboratory portion of the course provides hands-on application of fundamental techniques in synthetic biology research.
Requisites: Prerequisites, BIOL 101 and CHEM 101; corequisite, BIOL 202 and CHEM 102.
Grading status: Letter grade.

BMME 425. Biomedical Applications of Electromagnetics. 3 Credits.
This course is designed to introduce diagnostic and therapeutic applications of electrostatic, magnetostatic, quasi-static, and radio-frequency electromagnetic fields. Students are expected to gain a better understanding of the physics behind electromagnetic interactions with biological tissues, and become familiar with numerical skills and hardware fundamentals for bio-electromagnetic devices.
Requisites: Prerequisites, MATH 383, COMP 116 or BMME 201, and PHYS 117 or 119.
Grading status: Letter grade.

BMME 435. Biological Physics. 3 Credits.
How diffusion, entropy, electrostatics, and hydrophobicity generate order and force in biology. Topics include DNA manipulation, intracellular transport, cell division, molecular motors, single molecule biophysics techniques, nerve impulses, neuroscience.
Requisites: Prerequisites, PHYS 116 and 117, or PHYS 118 and 119.
Grading status: Letter grade
Same as: PHYS 405, BIOL 431.

BMME 441. Thermal Physics. 3 Credits.
Equilibrium statistical mechanics; the laws of thermodynamics, internal energy, enthalpy, entropy, thermodynamic potentials, Maxwell’s equations.
Requisites: Prerequisites, MATH 233, and PHYS 117 or 119; permission of the instructor for students lacking the prerequisites.
Grading status: Letter grade
Same as: PHYS 441.
BMME 445. Systems Neuroscience. 3 Credits.
Introduction to methodologies used to characterize a) the aggregate behavior of living neural networks and b) the changes in that behavior that occur as a function of stimulus properties, pharmacological manipulations, and other factors that dynamically modify the functional status of the network.
**Requisites:** Prerequisite, BIOL 252.
**Grading status:** Letter grade.

BMME 455. Biofluid Mechanics. 3 Credits.
This course introduces students to basics of fluid mechanics (steady and pulsatile flows, laminar and turbulent flows, and Newtonian and non-Newtonian flows). Students learn the fundamental relationships and governing equations describing these types of flows and the basic physiology of certain systems that are highly associated with fluid flows.
**Requisites:** Prerequisites, BMME 160, MATH 528, and BMME 201 or COMP 116.
**Grading status:** Letter grade.

BMME 465. Biomedical Instrumentation I. 4 Credits.
Topics include basic electronic circuit design, analysis of medical instrumentation circuits, physiologic transducers (pressure, flow, bioelectric, temperate, and displacement). This course includes a laboratory where the student builds biomedical devices. Note, an embedded computer kit purchase is required for this course.
**Requisites:** Prerequisites, BMME 350, and COMP 116 or BMME 201.
**Grading status:** Letter grade.

BMME 470. Tissue Engineering. 3 Credits.
Lectures in this course address how to quantitatively evaluate functional engineered tissues. The course provides an overview of the field, with emphasis on detailed evaluation of scientific and commercial progress over time, and design principles that must be met to develop a process or fabricate a functional tissue-engineered part.
**Requisites:** Prerequisites, BIOL 252 and BMME 351.
**Grading status:** Letter grade.

BMME 475. Transport Processes. 3 Credits.
This course serves as introduction for engineers pursuing transport phenomena and for future pharmaco-engineers requiring predictive models of mass transfer or pharmacodynamic models. Material is designed to address heat and mass transfer issues in nanotechnology, microfabrication, mems, cell therapies, bioartificial organs, as well as pharmacodynamic modeling of dynamic "omics" datasets.
**Grading status:** Letter grade.

BMME 485. Biotechnology. 3 Credits.
This course is designed to prepare a biomedical engineering student with the survey tools to understand key components in modern biotechnologies. Fundamental concepts, theory, design, operation, and analysis of the most common biotechnologies in bioengineering will be presented.
**Requisites:** Prerequisite, BMME 210.
**Grading status:** Letter grade.

BMME 490. Special Topics in Biomedical Engineering. 3-9 Credits.
A study in the special fields under the direction of the faculty. Offered as needed for presenting material not normally available in regular BMME courses.
**Repeat rules:** May be repeated for credit; may be repeated in the same term for different topics; 12 total credits. 4 total completions.
**Grading status:** Letter grade.

BMME 495. Undergraduate Research in Biomedical Engineering as a Technical Elective. 3 Credits.
Opportunity for hands-on faculty mentored research project in biomedical engineering. Approved plan of work required with significant independent research culminating in a final paper and presentation at an appropriate venue. Departmental approval required. Course may not be repeated.
**Grading status:** Letter grade.

BMME 505. Skeletal Biomechanics. 3 Credits.
A firm understanding of the principles of mechanics is an important foundation to biomechanics. In this course, students will study the mechanics of materials with applications to the strength of bone, implant analysis, and testing of biological materials. A goal of this course is for students to understand how the interface of biology, mechanics, and therapies affect skeletal pathological conditions.
**Requisites:** Prerequisites, BMME 160 and MATH 383.
**Grading status:** Letter grade.

BMME 510. Biomaterials. 3 Credits.
Focus on the mechanical, chemical, and biocompatibility considerations of any material (e.g., metal, ceramic, or polymer) designed to interface with the body. Various applications of biomaterials are presented and analyzed, including femoral implants and vascular grafts, in order to guide students in a semester-long design project.
**Requisites:** Prerequisites, BIOL 101 and BMME 150; corequisites BIOL 252 and 252L.
**Grading status:** Letter grade.

BMME 515. Introduction to Systems Biology. 3 Credits.
Cells, tissues, organs, and organisms have been shaped through evolutionary processes to perform their functions in robust, reliable manners. This course investigates design principles and structure-function relationships of biomolecular networks. Emphasis will be placed on gene- and protein-circuits and their role in controlling cellular behavior and phenotype.
**Requisites:** Prerequisite, MATH 383 or 528.
**Grading status:** Letter grade.

BMME 550. Medical Imaging I: Ultrasonic, Optical, and Magnetic Resonance Systems. 3 Credits.
Physical and mathematical foundations of ultrasonic, optical, and magnetic resonance imaging systems in application to medical diagnostics. Each imaging modality is examined, highlighting critical system characteristics: underlying physics of the imaging system, including mechanisms of data generation and acquisition; image creation; and relevant image processing methods, such as noise reduction.
**Requisites:** Prerequisites, BIOS 550, BMME 530, and PHYS 128.
**Grading status:** Letter grade.

BMME 551. Medical Device Design I. 3 Credits.
Student multidisciplinary teams work with local medical professionals to define specific medical device concepts for implementation.
**Grading status:** Letter grade.

BMME 552. Medical Device Design II. 3 Credits.
Device prototypes designed in the first course in series. Good manufacturing practices; process validation; FDA quality system regulations; design verification and validation; regulatory approval planning; and intellectual property protection.
**Grading status:** Letter grade.
BMME 560. Medical Imaging II: X-Ray, CT, and Nuclear Medicine Systems. 3 Credits.
**Requisites:** Prerequisites, BIOS 550, BMME 410, and PHYS 128.
**Grading status:** Letter grade.

BMME 565. Biomedical Instrumentation I. 4 Credits.
Graduate students or permission of the instructor. Topics include basic electronic circuit design, analysis of medical instrumentation circuits, physiologic transducers (pressure, flow, bioelectric, temperature, and displacement). This course includes a laboratory where the student builds biomedical devices.
**Grading status:** Letter grade.

BMME 576. Mathematics for Image Computing. 3 Credits.
Mathematics relevant to image processing and analysis using real image computing objectives and provided by computer implementations.
**Requisites:** Prerequisites, COMP 116 or 401, and MATH 233.
**Grading status:** Letter grade

Same as: COMP 576.

BMME 580. Microcontroller Applications I. 3 Credits.
Introduction to digital computers for real-time processing and control of signals and systems. Programming input and output devices using C and assembly language is stressed. Case studies are used to present software design strategies for real-time laboratory systems.
**Requisites:** Prerequisites, BIOL 252, BMME 350, and COMP 116 or BMME 201; co-requisite, BMME 351.
**Grading status:** Letter grade.

BMME 581. Microcontroller Applications II. 3 Credits.
Advanced topics in microcontroller systems used for biomedical instruments. Problems of interfacing computers with biomedical systems are studied. Students collaborate to develop a new biomedical instrument. Platforms could include the use of digital signal processing (DSP) microcontrollers or field programmable gate arrays (FPGAs), and topics could include applications such as digital signal processing and high speed data acquisition to computers.
**Requisites:** Prerequisites, BMME 465 and 580.
**Grading status:** Letter grade.

BMME 681. Human Factors Engineering and Quality Management Systems for Engineers. 3 Credits.
This course teaches human factors engineering, risk assessment, and quality management systems. At the end of the course, students will be able to apply their knowledge to their senior design project and test for a Six sigma green belt certification.
**Grading status:** Letter grade.

BMME 691H. Honors Thesis. 3 Credits.
Research honors course. Prior approval needed from the chair or associate chair of the program for topic selection and faculty research mentor. Minimum GPA requirement, written report, and abstract requirements as set forth by the honors program.
**Gen Ed:** EE-Mentored Research.
**Grading status:** Letter grade.

BMME 692H. Honors Thesis. 3 Credits.
Research honors thesis continuation with required GPA, research topic selection with approved faculty mentor. Written abstract and report per honors program guidelines submitted by specific deadlines.
**Gen Ed:** EE-Mentored Research.
**Grading status:** Letter grade.

BMME 697. Senior Design Project I. 3 Credits.
Course restricted to admitted majors only. Conceptual prelude and preparation to BMME 698, in which the theoretical and practical knowledge acquired during the undergraduate tenure is applied to develop a solution to a real-world problem.
**Requisites:** Prerequisites, BMME 310, BMME 351, and one BMME course above 400.
**Grading status:** Letter grade.

BMME 698. Senior Design Project II. 3 Credits.
Implementation phase of the senior design experience. Students apply the theoretical and practical knowledge they have acquired in their previous seven semesters to the design and implementation of a solution to a real-world problem.
**Requisites:** Prerequisite, BMME 697.
**Gen Ed:** CI, EE-Mentored Research.
**Grading status:** Letter grade.

Graduate-level Courses

BMME 740. Advanced Biomaterials. 3 Credits.
Medical or dental implants or explants are highlighted from textbooks, scientific literature, and personal accounts.
**Requisites:** Prerequisite, BMME 510; Permission of the instructor for students lacking the prerequisite.
**Same as:** MTSC 740.

BMME 770. Physiology and Methods in Genomics. 4 Credits.
Lectures in physiology systems and lab techniques covering various functional genomic methods including DNA sequencing, gene arrays, proteomics, confocal microscopy, and imaging modalities.

BMME 775. Image Processing and Analysis. 3 Credits.
**Requisites:** Prerequisites, COMP 665, MATH 547, and STOR 435.
**Same as:** COMP 775.

BMME 790. Graduate Systems Physiology. 3 Credits.
This is the second semester of the two-semester series intended to provide graduate students with an introduction to systems and organ physiology.
**Requisites:** Prerequisite, BMME 589.

BMME 795. Information Processing in the Central Nervous System. 3 Credits.
Introduction to methodologies used to characterize a) the aggregate behavior of living neural networks and b) the changes in that behavior that occurs as a function of stimulus properties, pharmacological manipulations, and other factors that dynamically modify the functional status of the network.
**Requisites:** Prerequisite, BMME 589.

BMME 810. Digital Nuclear Imaging. 3 Credits.
Advanced topics of physics and instrumentation in nuclear imaging and magnetic resonance techniques.
**Requisites:** Prerequisites, BMME 550 and 560.

BMME 840. Rehabilitation Engineering Design. 4 Credits.
Students will design an assistive technology device to help individuals with disabilities to become more independent. The project will be used in the community when it is completed.
**Requisites:** Prerequisite, BMME 465; Permission of the instructor for students lacking the prerequisite.
BMME 890. Special Topics. 1-21 Credits.
Permission of the instructor. Special library and/or laboratory work on an individual basis on specific problems in biomedical engineering and biomedical mathematics. Direction of students is on a tutorial basis and subject matter is selected on the basis of individual needs and interests.
Repeat rules: May be repeated for credit; may be repeated in the same term for different topics.

BMME 900. Research in Biomedical Engineering and Biomathematics. 1-21 Credits.
Permission of the instructor.

BMME 993. Master's Research and Thesis. 3 Credits.

BMME 994. Doctoral Research and Dissertation. 3 Credits.