Biomedical Engineering (BMEG)

Jeff Wolchok
Department Head
120 John A. White Jr. Engineering Hall
479-575-2850
Email: bmegrad@uark.edu

Kartik Balachandran
Graduate Coordinator
120 John A. White Jr. Engineering Hall
479-575-3376
Email: bmegrad@uark.edu

Biomedical Engineering Website (https://biomedical-engineering.uark.edu/)

Degrees Conferred:
M.S.B.M.E. (BMEGMS)
Ph.D. (BMEGPH) in Engineering

Primary Areas of Faculty Research: Bioimaging and biosensing; bioinformatics and computational biology; tissue engineering and biomaterials; bio-MEMS/nanotechnology.

Program Objectives: The objectives of the M.S.B.M.E. program are to prepare graduates for careers in biomedical engineering practice with government agencies, engineering firms, consulting firms or industries and to provide a foundation for continued study at the post-master's level.

M.S.B.M.E. in Biomedical Engineering

Admission to Degree Program: Admission to the M.S.B.M.E. is a two-step process. First, the prospective student must be admitted to graduate standing by the University of Arkansas Graduate School (see "The Graduate School: Objectives, Regulations, Degrees" in this catalog or visit grad.uark.edu (http://grad.uark.edu/) for details). Second, the student must be admitted to the Department of Biomedical Engineering on the basis of academic transcripts, standardized test scores, three letters of recommendation and a statement of purpose. Students with a non-engineering degree or a non-ABET-accredited engineering degree must demonstrate completion of the Minimum Admission Criteria for non-Engineering Majors prior to being admitted. Complete details for admission may be obtained in the applicable program section from the Biomedical Engineering website (http://bmeg.uark.edu/) as well as in the BMEG graduate program handbook. A general summary of admission requirements is given below:

1. A B.S. or M.S. degree in engineering or engineering equivalent or completion of the minimum admission criteria for non-engineering majors (see below) with a GPA of at least 3.0.
2. A GPA of 3.0 or higher on the last 60 hours of the baccalaureate degree.
3. A GRE score of 302 or above (verbal and quantitative).
4. A TOEFL score of at least 213 (computer-based) or 80 (internet based). This requirement is waived for applicants whose native language is English or who earn a bachelor's or master's degree from a U.S. institution.
5. A member of the faculty who is eligible (graduate status of group III or higher) must agree to serve as the Major Adviser to the prospective student.

Minimum Admission Criteria for non-Engineering Majors: Prior to gaining admission into the M.S.B.M.E. program, students with a non-engineering degree or a non-ABET-accredited engineering degree must demonstrate completion of the following coursework with a GPA of at least 3.0: 3 courses in Mathematics (selected from Calculus I, Calculus II, Calculus III, Linear Algebra, and/or Differential Equations), 2 courses of university-level Biology, 2 courses of university-level Chemistry, and 2 courses of university-level (calculus-based) Physics. In addition, students will be required to enroll and complete one of the following courses to provide adequate background in Engineering Design (BMEG 2904 Biomedical Instrumentation, BMEG 3634 Biomaterials, BMEG 3124 Biomedical Signals and Systems, or BMEG 3824 Biomolecular Engineering. Students should consult the Graduate Coordinator for a complete list of courses that satisfy the Minimum Admission Criteria.

Complete details for admission may be obtained in the applicable program section from the B (http://bmeg.uark.edu/)iomedical Engineering (http://bmeg.uark.edu/) website (http://bmeg.uark.edu/) as well as in the BMEG graduate program handbook.

Requirements for M.S. Degree in Biomedical Engineering: Both thesis and non-thesis options are available for the M.S.B.M.E. degree. In general, students pursuing the thesis option are supported by research or teaching assistantships and conduct research under the guidance of a major adviser. Students pursuing the non-thesis options are typically not sponsored. For either option, all course work must be approved by the student's program advisory committee. The cumulative grade-point average on all graduate courses presented for the degree must be at least 3.0. A general summary of degree requirements is given below. More detailed information may be obtained from the B (http://bmeg.uark.edu/)iomedical Engineering (http://bmeg.uark.edu/) website (http://bmeg.uark.edu/) as well as in the BMEG graduate program handbook. Students should also be aware of Graduate School requirements with regard to master's degrees (http://catalog.uark.edu/graduatecatalog/degreerequirements/#mastersdegreestext).

- **Biomedical Engineering Thesis Option**: 24 hours of graduate-level course work, including 5 hours of Biomedical Engineering Graduate Core as identified below, at least 10 additional hours of graduate-level classes in Biomedical Engineering, and 6 hours of research resulting in a written master's thesis. Candidates must pass a comprehensive final examination that will include an oral defense of the master's thesis. The examination is prepared and administered by the student's master's thesis committee. All coursework must be at the 5000 level or above unless a request has been approved to use 4000-level courses for graduate credit.
- **Biomedical Engineering Non-thesis Option**: 30 hours of graduate-level course work including 5 hours of Biomedical Engineering Graduate Core as identified below, at least 10 additional hours of graduate-level classes in Biomedical Engineering. Candidates must pass a comprehensive written final examination. The examination is prepared and administered by the student's Program Advisory Committee. All coursework must be at the 5000 level or above unless a request has been approved to use 4000-level courses for graduate credit.

Biomedical Engineering Graduate Core

BMEG 5103	Design and Analysis of Experiments in Biomedical Research	3
BMEG 5801	Graduate Seminar I	1
BMEG 5811	Graduate Seminar II	1

Accelerated M.S.B.M.E. Degree

High-achieving current undergraduate students seeking a B.S.B.M.E. degree at the University of Arkansas who choose to pursue graduate studies in Biomedical Engineering may participate in the accelerated M.S.B.M.E. program. Eligible students may take up to 12 credit hours of 5000-level courses as BMEG or science electives for their bachelor's degree and those hours will also count towards their M.S.B.M.E. degree. The total of 12 credit hours of graduate courses taken as an undergraduate student must be taken during the final 12-month period of their undergraduate degree.

Once fully admitted to the M.S.B.M.E. program, students will request that up to 12 hours of 5000-level or above courses taken in the final 12-month period of their undergraduate degree count toward their graduate degree, if these courses were taken on the Fayetteville campus of the University of Arkansas. Students then take an additional 18 credit hours of approved BMEG graduate-level courses (including BMEG 600V Master's Thesis if required) in order to complete their M.S.B.M.E. degree as per their intended M.S.B.M.E program (i.e. Thesis options, Non-thesis option or Healthcare Entrepreneurship option).

Biomedical engineering undergraduate students interested in the accelerated M.S.B.M.E. degree should apply to the program prior to starting the second-to-last semester of their undergraduate program. To be eligible, students must have a 3.5 cumulative GPA or higher and submit the normal application materials required by the graduate school for the M.S.B.M.E. degree program. For students that have a cumulative GPA of 3.5 or higher, the submission of GRE scores is waived.

Students should also be aware of Graduate School requirements with regard to master's degrees (https://catalog.uark.edu/graduatecatalog/degreerequirements/#mastersdegreestext).

Requirements for M.S.B.M.E. in Biomedical Engineering with Healthcare Entrepreneurship Concentration

Admission to Degree Program: Admission to the M.S.B.M.E. is a two-step process. First, the prospective student must be admitted to graduate standing by the University of Arkansas Graduate School (see "The Graduate School: Objectives, Regulations, Degrees" in this catalog or visit grad.uark.edu (http://grad.uark.edu/) for details). Second, the student must be admitted to the Department of Biomedical Engineering on the basis of academic transcripts, standardized test scores, three letters of recommendation and a statement of purpose. Students with a non-engineering degree or a non-ABET-accredited engineering degree must demonstrate completion of the Minimum Admission Criteria for non-Engineering Majors prior to being admitted. Complete details for admission may be obtained in the applicable program section from the Biomedical Engineering website (http://bmeg.uark.edu/) as well as in the BMEG graduate program handbook. A general summary of admission requirements is given below:

1. A B.S. or M.S. degree in engineering or engineering equivalent or completion of the minimum admission criteria for non-engineering majors (see below) with a GPA of at least 3.0.
2. A GPA of 3.0 or higher on the last 60 hours of the baccalaureate degree.
3. A GRE score of 302 or above (verbal and quantitative).
4. A TOEFL score of at least 213 (computer-based) or 80 (internet based). This requirement is waived for applicants whose native language is English or who earn a bachelor's or master's degree from a U.S. institution.
5. A member of the faculty who is eligible (graduate status of group III or higher) must agree to serve as the Major Adviser to the prospective student.

Minimum Admission Criteria for non-Engineering Majors: Prior to gaining admission into the M.S.B.M.E. program, students with a non-engineering degree or a non-ABET-accredited engineering degree must demonstrate completion of the following coursework with a GPA of at least 3.0: 3 courses in Mathematics (selected from Calculus I, Calculus II, Calculus III, Linear Algebra, and/or Differential Equations), 2 courses of university-level Biology, 2 courses of university-level Chemistry, and 2 courses of university-level (calculus-based) Physics. In addition, students will be required to enroll and complete one of the following courses to provide adequate background in Engineering Design (BMEG 2904 Biomedical Instrumentation, BMEG 3634 Biomaterials, BMEG 3124 Biomedical Signals and Systems, or BMEG 3824 Biomolecular Engineering. Students should consult the Graduate Coordinator for a complete list of courses that satisfy the Minimum Admission Criteria.

Complete details for admission may be obtained in the applicable program section from the B (http://bmeg.uark.edu/)iomedical Engineering (http://bmeg.uark.edu/) website (http://bmeg.uark.edu/) as well as in the BMEG graduate program handbook.

Requirements for M.S. Degree in Biomedical Engineering: Both thesis and non-thesis options are available for the M.S.B.M.E. degree. In general, students pursuing the thesis option are supported by research or teaching assistantships and conduct research under the guidance of a major adviser. Students pursuing the non-thesis options are typically not sponsored. For either option, all course work must be approved by the student's program advisory committee. The cumulative grade-point average on all graduate courses presented for the degree must be at least 3.0. A general summary of degree requirements is given below. More detailed information may be obtained from the B (http://bmeg.uark.edu/)iomedical Engineering (http://bmeg.uark.edu/) website (http://bmeg.uark.edu/) as well as in the BMEG graduate program handbook. Students should also be aware of Graduate School requirements with regard to master's degrees (http://catalog.uark.edu/graduatecatalog/degreerequirements/#mastersdegreestext).

- **Biomedical Engineering Thesis Option**: 24 hours of graduate-level course work, including 5 hours of Biomedical Engineering Graduate Core as identified below, at least 10 additional hours of graduate-level classes in Biomedical Engineering, and 6 hours of research resulting in a written master's thesis. Candidates must pass a comprehensive final examination that will include an oral defense of the master's thesis. The examination is prepared and administered by the student's master's thesis committee. All coursework must be at the 5000 level or above unless a request has been approved to use 4000-level courses for graduate credit.
- **Biomedical Engineering Non-thesis Option**: 30 hours of graduate-level course work including 5 hours of Biomedical Engineering Graduate Core as identified below, at least 10 additional hours of graduate-level classes in Biomedical Engineering. Candidates must pass a comprehensive written final examination. The examination

is prepared and administered by the student's Program Advisory Committee. All coursework must be at the 5000 level or above unless a request has been approved to use 4000-level courses for graduate credit.

Biomedical Engineering Graduate Core

BMEG 5103	Design and Analysis of Experiments in Biomedical Research	3
BMEG 5801	Graduate Seminar I	1
BMEG 5811	Graduate Seminar II	1

Accelerated M.S.B.M.E. Degree

High-achieving current undergraduate students seeking a B.S.B.M.E. degree at the University of Arkansas who choose to pursue graduate studies in Biomedical Engineering may participate in the accelerated M.S.B.M.E. program. Eligible students may take up to 12 credit hours of 5000-level courses as BMEG or science electives for their bachelor's degree and those hours will also count towards their M.S.B.M.E. degree. The total of 12 credit hours of graduate courses taken as an undergraduate student must be taken during the final 12-month period of their undergraduate degree.

Once fully admitted to the M.S.B.M.E. program, students will request that up to 12 hours of 5000-level or above courses taken in the final 12-month period of their undergraduate degree count toward their graduate degree, if these courses were taken on the Fayetteville campus of the University of Arkansas. Students then take an additional 18 credit hours of approved BMEG graduate-level courses (including BMEG 600V Master's Thesis if required) in order to complete their M.S.B.M.E. degree as per their intended M.S.B.M.E program (i.e. Thesis options, Non-thesis option or Healthcare Entrepreneurship option).

Biomedical engineering undergraduate students interested in the accelerated M.S.B.M.E. degree should apply to the program prior to starting the second-to-last semester of their undergraduate program. To be eligible, students must have a 3.5 cumulative GPA or higher and submit the normal application materials required by the graduate school for the M.S.B.M.E. degree program. For students that have a cumulative GPA of 3.5 or higher, the submission of GRE scores is waived.

Students should also be aware of Graduate School requirements with regard to master's degrees (https://catalog.uark.edu/graduatecatalog/degreerequirements/#mastersdegreestext).

Healthcare Entrepreneurship Concentration

The Healthcare Entrepreneurship Concentration requires 15 additional hours of required courses and 10 additional hours of graduate-level classes in Biomedical Engineering. Candidates must pass a comprehensive written final examination. The examination is prepared and administered by the student's Program Advisory Committee. All coursework must be at the 5000 level or above unless a request has been approved to use 4000-level courses for graduate credit.

Business and Management Fundamentals		
SEVI 5213	Business Foundations for Entrepreneurs	3
New Venture Development		
The following courses have to be taken in one continuous block		
SEVI 5323	New Venture Development	3
SEVI 5313	Strategic Management	3
SEVI 5413		3
Public Health Fundamentals		
Choose at least one course from below or another relevant course with Program Advisory Committee approval		3
PBHL 5213		
PBHL 5533	Theories of Social and Behavioral Determinants of Health	
PBHL 5563	Public Health: Practices and Planning	
Graduate-level Electives		**10**

Ph.D. in Engineering

Program Description: The Ph.D. Degree in Engineering with a concentration in Biomedical Engineering is an interdisciplinary research degree awarded through the College of Engineering in cooperation with the Graduate School (at the University of Arkansas, there is a common Ph.D. degree for all engineering disciplines). The Ph.D. degree is earned through advanced coursework and in-depth, specialized research. Graduates from this program will be well-prepared for careers in academia, industry or government or as entrepreneurs in technology-based start-up companies.

Admission to Degree Program: Admission into the Ph.D. program with a concentration in Biomedical Engineering is a two-step process. First, the prospective student must be admitted to graduate standing by the University of Arkansas Graduate School (see "The Graduate School: Objectives, Regulations, Degrees" in this catalog or visit grad.uark.edu (http://grad.uark.edu/) for details). Second, the student must be admitted to the Department of Biomedical Engineering on the basis of academic transcripts, standardized test scores, three letters of recommendation, and statement of purpose. All students in the Ph.D. program are offered either a research or teaching assistantship. A member of the faculty who is eligible (graduate faculty status of Group I), must agree to serve as the major adviser to the prospective student. Because of the multidisciplinary nature of Biomedical Engineering, students holding either Engineering or non-Engineering degrees are eligible to apply. Eligibility criteria are outlined below:

- Engineering Academic Background: Students with a B.S. or M.S. degree in engineering or engineering equivalent are eligible to apply for the Ph.D. program.
- Non-engineering Academic Background: Students with a non-engineering degree must fulfill the admission requirements for the Master of Science in Biomedical Engineering (M.S.B.M.E.) including the Minimum Admission Criteria for non-Engineering Majors (see admission requirements for the M.S.B.M.E.). Students with a non-engineering background may be admitted directly into the Ph.D. program; however, it is recommended that students first complete the M.S.B.M.E. degree before entering the Ph.D. program.

Complete details for admission may be obtained in the applicable section from the B (http://bmeg.uark.edu)iomedical Engineering (http://bmeg.uark.edu/) website (http://bmeg.uark.edu) as well as in the BMEG graduate program handbook.

Degree Requirements for the Doctor of Philosophy in Engineering with a concentration in Biomedical Engineering: In addition to the requirements of the Graduate School and the College of Engineering, candidates must meet the following requirements:

1. Develop a Plan of Study within the first year after matriculation.
2. Complete an Annual Progress Report for each subsequent year of study.

3. Complete at least 29 total hours of graduate-level course work beyond the B.S. degree.
   a. For B.S. to Ph.D. candidates, a minimum of 50 percent of the first 30 hours, and all of the remaining hours of course work, must be at the 5000 level or above.
   b. For M.S. to Ph.D. candidates, all course work must be at the 5000 level or above.
4. Complete 5 hours of BMEG Graduate Core Courses as listed below, as part of the minimum 29 hours of course work.
5. The cumulative grade-point average on all graduate courses presented for the degree must be at least 3.0. Upon recommendation of the student's Program Advisory Committee, a student who has entered the Ph.D. program after an M.S. degree in engineering may receive credit for up to 24 hours of course work. See Coursework Requirements, below, for additional details.
6. Complete at least 30 hours of dissertation. Upon recommendation of the student's Program Advisory Committee, a student who has entered the Ph.D. program after an M.S. degree in engineering may receive credit for up to 6 hours of thesis research toward the dissertation requirement.
7. Students must complete a minimum of 72 graduate-level credit hours beyond the bachelor's degree and 42 graduate-level credit hours beyond the master's degree.
8. Satisfactorily pass both a written and oral candidacy examination administered by the student's Program Advisory Committee. Details of the candidacy exam are found in the BMEG graduate program handbook.
9. Assist in departmental teaching for two semesters.
10. Submit and defend the final dissertation to the student's Dissertation Committee.

Coursework Requirements: Students are required to complete at least 29 credit hours of coursework beyond the B.S. degree. At least 26 hours of coursework must comprise the following four categories.

Biomedical Engineering Graduate Core (5 hours)		
BMEG 5103	Design and Analysis of Experiments in Biomedical Research	3
BMEG 5801	Graduate Seminar I	1
BMEG 5811	Graduate Seminar II	1
Life Science – minimum of six hours approved by the student's Program Advisory Committee		6
Engineering Electives – minimum of nine hours approved by the student's Program Advisory Committee		9
BMEG Electives – minimum of six hours of graduate-level classes in Biomedical Engineering approved by the student's Program Advisory Committee		6
Total Hours		**26**

Detailed degree requirements may be obtained in the applicable program section from the B (http://bmeg.uark.edu)iomedical Engineering (http://bmeg.uark.edu/) website (http://bmeg.uark.edu) as well as in the Biomedical Engineering graduate program handbook.

Students should also be aware of Graduate School requirements with regard to doctoral degrees (http://catalog.uark.edu/graduatecatalog/degreerequirements/#phdandedddegreestext).

Graduate Faculty

Abbas, James, Ph.D., M.S. (Case Western Reserve University), Sc.B. (Brown University), Professor, 2021.
Balachandran, Kartik, Ph.D., M.S. (Georgia Institute of Technology), B.S. (National University of Singapore), Associate Professor, 2012, 2018.
Elsaadany, Mostafa, Ph.D. (University of Toledo), Teaching Assistant Professor, 2019.
Harris, Leonard, Ph.D. (Cornell University), B.S. (University of Colorado, Boulder), Assistant Professor, 2020.
Jensen, Hanna Katariina, Ph.D. (University of Oulu, Finland), Research Assistant Professor, 2015.
Jensen, Morten O., Ph.D. (University of Aarhus, Denmark), M.Sc. (Georgia Institute of Technology), Associate Professor, 2014.
Muldoon, Timothy J., M.D. (Baylor College of Medicine), Ph.D. (Rice University), B.S. (Johns Hopkins University), Associate Professor, 2012, 2018.
Nelson, Christopher, Ph.D. (Vanderbilt University), Assistant Professor, 2019.
Puvanakrishnan, Priyaveena, Ph.D. (University of Texas at Austin), Instructor, 2015.
Qian, Xianghong, Ph.D., M.Phil. (George Washington University), B.S. (Nanjing University, P.R. China), Professor, 2011, 2016.
Quinn, Kyle P., Ph.D. (University of Pennsylvania), B.S. (University of Wisconsin), Assistant Professor, 2014.
Rajaram, Narasimhan, Ph.D. (University of Texas, Austin), B.E. (Anna University, India), Assistant Professor, 2014.
Rao, Raj R., Ph.D. (University of Georgia), M.S. (University of Texas), M.Sc., B.E. (Birla Institute of Technology and Sciences, India), Professor, 2016.
Samsonraj, Rebekah M., Ph.D. (Cornell University), B.S. (University of Colorado, Boulder), Assistant Professor, 2020.
Song, Young Hye, Ph.D. (Cornell University), Assistant Professor, 2019.
Wolchok, Jeffrey Collins, Ph.D. (University of Utah), M.S., B.S. (University of California at Davis), Associate Professor, 2011, 2017.

Courses

BMEG 5103. Design and Analysis of Experiments in Biomedical Research. 3 Hours.
An advanced course covering sample size estimation with power calculations, protection of vertebrate animals and human subjects, factorial design, multivariate analysis of variance, parametric and non-parametrics data analysis, Kaplan-meier analysis, and post-test correction of multiple comparisons as related to biomedical data. Prerequisite: MATH 2584 and BMEG 3653 or equivalents. (Typically offered: Irregular)

BMEG 5213. Tissue Mechanics. 3 Hours.
The purpose of this course is to introduce students to non-linear biomechanics of soft tissues such as skin, bladder, blood vessels, and the brain. Topics covered: Tissue mechanics: continuum biomechanics, tensor analysis, kinematics of continua, balance laws. Governing physics of mechanics as applied to soft tissues. Various constitutive relations will be discussed: linear elastic, hyperelastic, viscoelastic, poroelastic, and inelastic materials with internal variables. Cannot receive credit for both BMEG 4213 and BMEG 5213. Prerequisite: BMEG 2813 and BMEG 4623 or equivalents. (Typically offered: Irregular)

BMEG 5223. Genome Engineering and Synthetic Biology. 3 Hours.
Genome Engineering and Synthetic Biology provides an overview of contemporary topics in genome engineering and synthetic biology. This course will introduce a range of topics in synthetic biology and genome engineering using recently published literature and publicly available data sets and software. In this rapidly evolving field, an ethics discussion will be held at the end of the course on potential topics including human embryo editing, genomic data privacy, patent claims, and GMOs. Students may not receive credit for both BMEG 4983 and BMEG 5223. Prerequisite: BMEG 3653 or DASC 3213. (Typically offered: Spring)

BMEG 5253. Biologics: Next Generation Therapeutics and Their Purification. 3 Hours.
The course focuses on the production and purification of biologics including monoclonal antibodies, viral vectors, nucleic acids and other biotherapeutics. In particular, the course will focus on the fundamental thermodynamics principles as well as kinetic limitations involved in upstream harvesting and downstream purification. Applications of PCR, mass spectroscopy, electrophoresis, imaging and modeling tools during the production and purification of biologics will be discussed. Students may not receive credit for both BMEG 4253 and BMEG 5253. (Typically offered: Irregular)

BMEG 5313. Advanced Biomaterials and Biocompatibility. 3 Hours.
From Absorbable sutures to Zirconium alloy hip implants, biomaterials science influences nearly every aspect of medicine. This course focuses on the study of different classes of biomaterials and their interactions with human tissues. Prerequisite: BMEG 3634 and BMEG 4623 or equivalents. (Typically offered: Irregular)

BMEG 5413. Tissue Engineering. 3 Hours.
This course introduces Tissue Engineering approaches at genetic and molecular, cellular, tissue, and organ levels. Topics include cell and tissue in-vitro expansion, tissue organization, signaling molecules, stem cell and stem cell differentiation, organ regeneration, biomaterial and matrix for tissue engineering, bioreactor design for cell and tissue culture, dynamic and transportation in cell and tissue cultures, clinical implementation of tissue engineered products, and tissue-engineered devices. Students may not earn credit for both BMEG 5413 and BMEG 4413. Prerequisite: BIOL 2533 and BMEG 3824. (Typically offered: Irregular)

BMEG 5423. Regenerative Medicine. 3 Hours.
The course covers five broad areas: Biological and molecular basis for regenerative medicine, tissue development, regenerative medicine and innovative technologies, clinical applications of regenerative medicine, and regulation and ethics. Prerequisite: BIOL 2533 and BMEG 3824 or equivalents. (Typically offered: Irregular)

BMEG 5513. Biomedical Optics and Imaging. 3 Hours.
This course will provide students with a fundamental understanding of various biomedical imaging modalities. Topics will include: Basics of light-tissue interaction - absorption, fluorescence, elastic and inelastic scattering; Computational and analytical models of light propagation to quantify tissue optical properties; Optical imaging techniques - spectroscopy, tomography, and laser speckle with potential clinical applications; and Clinical imaging modalities and recent advances - X-ray, Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), Computed Tomography (CT), Ultrasound imaging, and Photoacoustic imaging. At the end of this course, students should have a good understanding of optical imaging, spectroscopy, and non-optical imaging modalities, specific anatomical sites that they are best suited for, and the trade-offs between imaging depth and resolution. Students may not receive credit for both BMEG 4513 and BMEG 5513. (Typically offered: Irregular)

BMEG 5523. Biomedical Data and Image Analysis. 3 Hours.
This course focuses on an introduction to image processing and analysis for applications in biomedical research. After a review of basic MATLAB usage, students will learn fundamental tools for processing and analyzing data from a variety of subdisciplines within biomedical engineering. Topics include: filtering, thresholding, segmentation, morphological processing, and image registration. Through exercises involving 1D, 2D, and 3D data, students will develop problem-solving skills and a knowledge base in MATLAB required for customized quantitative data analysis. Students may not receive credit for both BMEG 4523 and BMEG 5523. Prerequisite: Graduate standing. (Typically offered: Irregular)

BMEG 560V. Advanced Individual Study. 1-6 Hour.
Individual study and research of a topic mutually agreeable to the student and faculty member. Prerequisite: Graduate standing. (Typically offered: Irregular)

BMEG 570V. Advanced Special Topics. 1-6 Hour.
Consideration of current biomedical engineering topics not covered in other courses. Prerequisite: Graduate standing. (Typically offered: Irregular) May be repeated for up to 15 hours of degree credit.

BMEG 5713. Cardiovascular Physiology and Devices. 3 Hours.
Understanding etymology of disease while creating solutions and dedicated devices is the primary focus of biomedical engineering. This course describes an interdisciplinary approach of the clinical and engineering worlds to develop devices for treating cardiovascular disease. The first part of the course will be a thorough review of the relevant anatomic and physiological considerations important for developing devices. Understanding these considerations from an engineering perspective to inform device development will be the second part of the course. Students may not receive credit for both BMEG 4713 and BMEG 5713. Prerequisite: Graduate standing. (Typically offered: Irregular)

BMEG 5800. Graduate Seminar I. 0 Hours.
A weekly seminar series comprised of presentations by invited speakers and graduate students as well as didactic instruction in relevant topics including research ethics, authorship, biosafety and the use of animals in biomedical research. Prerequisite: BMEG 5801. (Typically offered: Fall) May be repeated for up to 0 hours of degree credit.

BMEG 5801. Graduate Seminar I. 1 Hour.
A weekly seminar series comprised of presentations by invited speakers and graduate students as well as didactic instruction in relevant topics including research ethics, authorship, biosafety and the use of animals in biomedical research. (Typically offered: Fall) May be repeated for up to 2 hours of degree credit.

BMEG 5810. Graduate Seminar II. 0 Hours.
A weekly seminar series comprised of presentations by invited speakers and graduate students as well as didactic instruction in relevant topics including professional development, career options, effective communication, technology transfer, clinical translation and intellectual property. Prerequisite: BMEG 5811. (Typically offered: Spring) May be repeated for up to 0 hours of degree credit.

BMEG 5811. Graduate Seminar II. 1 Hour.
A weekly seminar series comprised of presentations by invited speakers and graduate students as well as didactic instruction in relevant topics including professional development, career options, effective communication, technology transfer, clinical translation and intellectual property. (Typically offered: Spring) May be repeated for up to 2 hours of degree credit.

BMEG 5903. Entrepreneurial Bioengineering. 3 Hours.
The course introduces entrepreneurship, business model canvas, and lean start-up principles to the students with a focus on medical device customer discovery and technology commercialization. Graduate degree credit will not be awarded for BMEG 4903. Degree credit will not be awarded for both BMEG 4903 and BMEG 5903. (Typically offered: Irregular)

BMEG 5953. Fundamentals of Fracture and Fatigue in Structures. 3 Hours.
The course will cover the concepts of linear-elastic, elastic-plastic and time-dependent Fracture Mechanics as applied to fracture in a variety of materials, structures, and operating conditions. The examples will include fracture in large components such as aircraft, bridges and pressure vessels and also in bones and in soft materials and human tissue. Prerequisite: Graduate standing in Civil, Mechanical or Biomedical Engineering or consent of the instructor. (Typically offered: Fall and Spring)
This course is cross-listed with MEEG 5953, CVEG 5953.

BMEG 600V. Master's Thesis. 1-6 Hour.
Master's Thesis. Prerequisite: Graduate standing. (Typically offered: Irregular) May be repeated for degree credit.

BMEG 700V. Doctoral Dissertation. 1-6 Hour.
Doctoral Dissertation. Prerequisite: Graduate standing. (Typically offered: Irregular) May be repeated for degree credit.