Biomedical Engineering Program
2123G Engineering Systems Building
757-683-3752
www.odu.edu/eng/programs/biomedical/
Dean Kruisienki, Graduate Program Director

Biomedical Engineering Program General Description
The Biomedical Engineering graduate degree programs are available to full-time and part-time students seeking to improve their research and professional skills in biomedical engineering. The programs strive to provide the highest quality engineering education at the graduate level, to engage in scholarly research at the forefront of biomedical engineering, and to serve the profession of biomedical engineering. Cutting-edge research opportunities and instruction are offered in:

- Bioelectrics and Pulsed Power
- Cellular & Molecular Bioengineering
- Cardiovascular Engineering
- Medical Image Analysis and Simulation
- Musculoskeletal Biomechanics
- Neural Engineering
- Plasma Medicine
- Systems Biology & Computational Bioengineering

Facilities: The Advanced Signal Processing in Engineering and Neuroscience (ASPIEN) Laboratory; the Biomachina Laboratory; the Biomechanics Laboratory; the Cardiac Electrophysiology Laboratory; the Cellular Mechanobiology Laboratory; the Medical Imaging, Diagnosis and Analysis (MIDA) Laboratory; the Medical Simulations Laboratory; the Plasma Engineering and Medicine Institute (PEMI); the Systems Analysis of Metabolic Physiology and Exercise (SAMPE) Laboratory; and the Virginia Institute for Imaging and Vision Analysis (VIIVA).

The program also has strong ties to several other on- and off-campus laboratories including the Applied Research Center at the Jefferson National Laboratory, the Center for Brain Research and Rehabilitation, the Frank Reidy Research Center for Bioelectrics, and the Virginia Modeling, Analysis and Simulation Center (VMASC). The program is supported by regional, national, and international clinical collaborators. These unique resources position the biomedical engineering program to be a leader in education and research in the Southeast and nationally.

List of Degrees and Certificates
- Master of Engineering – Biomedical Engineering
- Master of Science, Engineering – Biomedical Engineering
- Doctor of Philosophy, Engineering – Biomedical Engineering
- Advanced Engineering Certificate – Biomedical Engineering

Master of Engineering - Biomedical Engineering

Master of Engineering Admission Requirements
Admission to the Master of Engineering program in biomedical engineering is in accordance with Old Dominion University and Frank Batten College of Engineering and Technology requirements for master’s programs as specified in this catalog. Specific additional requirements include the following:

1. Completion of a bachelor’s degree in Engineering, Science or Mathematics from an accredited institution, although students from other educational backgrounds may apply with appropriate leveling courses.

2. A minimum GPA of 3.00 (out of 4.0) is required of most students. A student with a lower GPA meeting ODU’s graduate admission requirements and with evidence of a high level of professional capability may be eligible for admission to the program upon submission of a petition to the graduate program director.

3. Recent scores, typically, not more than five years old, on the Graduate Record Examination’s (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.

4. Two letters of recommendation (typically from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are encouraged but not required.

5. The applicant must submit a resume and a statement of purpose and goals.

6. Foundation knowledge in physics, basic chemistry, computer programming, and mathematics (including differential equations) is expected.

Master of Engineering Degree Requirements
The Master of Engineering program requires completion of 10 three-credit courses: two BME fundamentals courses, a graduate physiology course, and seven technical electives. The seven technical electives should be chosen to meet the student’s career objectives.

BME Fundamentals "
- BME 501 Biomedical Engineering I: Principles
- BME 502 Biomedical Engineering II: Applications

Graduate Human Biology or Physiology**
- BME 720 Modern Biomedical Instrumentation
- BME 721 Mathematical Modeling in Physiology I
- BME 722 Mathematical Modeling in Physiology II
- BME 724 Neural Engineering
- BME 751 Computational and Statistical Methods in Biomedical Engineering
- BME 762 Applied Medical Image Analysis
- BME 795 Special Topics in Biomedical Engineering

Approved Technical Electives ***
- BME 564 Biomedical Applications of Low Temperature Plasmas
- BME 562 Introduction to Medical Image Analysis
- BME 554 Introduction to Bioelectrics
- BME 502 Biomedical Engineering II: Applications
- BME 501 Biomedical Engineering I: Principles
- BME 562 Introduction to Medical Image Analysis
- BME 564 Biomedical Applications of Low Temperature Plasmas
- BME 564 Biomedical Applications of Low Temperature Plasmas
- BME 501 Biomedical Engineering I: Principles
- BME 502 Biomedical Engineering II: Applications
- BME 502 Biomedical Engineering II: Applications
- BME 501 Biomedical Engineering I: Principles
- BME 502 Biomedical Engineering II: Applications

Total Hours
- 30

* Students who have completed BME 401 or BME 402 as part of a previous degree, program, or minor may substitute these courses with graduate-level BME electives approved by the graduate program director.

** Select one graduate course on human biology or physiology to be approved by the graduate program director.

*** The technical elective courses can be selected from the biomedical engineering technical electives or a wide variety of appropriate graduate courses in engineering, biology, chemistry, psychology, computer science, modeling and simulation, mathematics, statistics, or other programs. Technical electives without the BME prefix must be approved by the graduate program director.

Master of Science, Engineering - Biomedical Engineering

Master of Science Admission Requirements
Admission to the Master of Science, Engineering - Biomedical Engineering program is in accordance with Old Dominion University and Frank Batten
College of Engineering and Technology requirements for master’s programs as specified in this catalog. Specific additional requirements include the following:

1. Completion of a bachelor’s degree in Engineering, Science or Mathematics from an accredited institution, although students from other educational backgrounds may apply with appropriate leveling courses.

2. A minimum GPA of 3.00 (out of 4.0) is required of most students. A student with a lower GPA meeting ODU’s graduate admission requirements and with evidence of a high level of professional capability may be eligible for admission to the program upon submission of a petition to the graduate program director.

3. Recent scores, typically, not more than five years old, on the Graduate Record Examination’s (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.

4. Two letters of recommendation (typically from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are encouraged but not required.

5. The applicant must submit a resume and a statement of purpose and goals.

6. Foundation knowledge in physics, basic chemistry, computer programming, and mathematics (including differential equations) is expected.

**Master of Science Degree Requirements**

The Master of Science program requires completion of 8 three-credit courses and 6 thesis research credits. The five technical electives should be chosen to meet the student’s research and career objectives.

<table>
<thead>
<tr>
<th>BME Fundamentals*</th>
<th>6</th>
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<tbody>
<tr>
<td>BME 501</td>
<td>Biomedical Engineering I: Principles</td>
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<tr>
<td>BME 502</td>
<td>Biomedical Engineering II: Applications</td>
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<tr>
<th>Graduate Human Biology or Physiology**</th>
<th>3</th>
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<tbody>
<tr>
<td>BME 554</td>
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<tr>
<td>BME 612</td>
<td>Digital Signal Processing I</td>
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<tr>
<td>BME 720</td>
<td>Modern Biomedical Instrumentation</td>
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<tr>
<td>BME 721</td>
<td>Mathematical Modeling in Physiology I</td>
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<tr>
<td>BME 722</td>
<td>Mathematical Modeling in Physiology II</td>
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<tr>
<td>BME 724</td>
<td>Neural Engineering</td>
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<tr>
<td>BME 751</td>
<td>Computational and Statistical Methods in Biomedical Engineering</td>
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<tr>
<td>BME 795</td>
<td>Special Topics in Biomedical Engineering</td>
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</table>

**BME Technical Electives (Choose Three)**

| BME 402                               | Computational and Statistical Methods in Biomedical Engineering |
| BME 420                               | Advanced Electromagnetics in Biology and Medicine |
| BME 422                               | Advanced Biomechanics and Tissue Engineering |
| BME 501                               | Biomedical Engineering I: Principles |
| BME 502                               | Biomedical Engineering II: Applications |
| BME 520                               | Advanced Biophysics: Modern Topics in the Physical Basis of Disease Processes |
| BME 522                               | Advanced Biostatistics |
| BME 524                               | Advanced Biomedical Instrumentation |
| BME 553                               | Advanced Biomedical Signal Processing |
| BME 564                               | Biomedical Applications of Low Temperature Plasmas |
| BME 612                               | Digital Signal Processing I |
| BME 620                               | Advanced Microscopy and Biomedical Imaging |
| BME 622                               | Advanced Biomedical Image Processing and Computer Vision |
| BME 624                               | Advanced Neuroimaging and Image Analysis |
| BME 651                               | Advanced Biomedical Informatics |
| BME 662                               | Advanced Biomedical Engineering I: Principles |
| BME 663                               | Advanced Biomedical Engineering II: Applications |
| BME 680                               | Advanced Computational Biomechanics |
| BME 681                               | Advanced Biomedical Signal Processing |
| BME 682                               | Advanced Biomedical Instrumentation |
| BME 683                               | Advanced Biostatistics |
| BME 684                               | Advanced Biomedical Image Processing and Computer Vision |
| BME 685                               | Advanced Neuroimaging and Image Analysis |
| BME 686                               | Advanced Biomedical Informatics |
| BME 687                               | Advanced Biomedical Engineering I: Principles |
| BME 688                               | Advanced Biomedical Engineering II: Applications |
| BME 699                               | Advanced Computational Biomechanics |

**Approved Technical Electives***

| BME 699 Thesis | 6 |

**Total Hours**

30

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* Students who have completed BME 401 or BME 402 as part of a previous degree, program, or minor may substitute these courses with graduate-level BME electives approved by the graduate program director.

** Select one graduate course on human biology or physiology to be approved by the graduate program director.

*** The technical elective courses can be selected from the biomedical engineering technical electives or a wide variety of appropriate graduate courses in engineering, biology, chemistry, psychology, computer science, modeling and simulation, mathematics, statistics, or other programs. Technical electives without the BME prefix must be approved by the graduate program director.

**Doctor of Philosophy, Engineering - Biomedical Engineering**

**Doctor of Philosophy Admission Requirements**

Admission to the Ph.D. program in biomedical engineering is in accordance with Old Dominion University and Frank Batten College of Engineering and Technology requirements for doctoral programs as specified in this catalog. Specific additional requirements include the following:

1. Completion of a master’s degree in a closely related field is expected. However, students who have completed 24 credits of graduate courses in an appropriate field from an accredited institution or have demonstrated an exceptionally high level of academic capability may petition for direct admittance into the program.

2. A minimum GPA of 3.50 (out of 4.0) is required of most students. A student with a lower GPA meeting ODU’s graduate admission requirements and with evidence of a high level of professional capability may be eligible for admission to the program upon submission of a petition to the graduate program director.

3. Recent scores, typically, not more than five years old, on the Graduate Record Examination’s (GRE) verbal, quantitative, and analytical writing sections must be submitted by all applicants.

4. Three letters of recommendation (typically at least two of which are from faculty in the highest degree program completed when the application is within five years of graduation from that degree program) are encouraged but not required.

5. The applicant must submit a resume and a statement of purpose and goals.

6. Foundation knowledge in physics, basic chemistry, computer programming, and mathematics (including differential equations) is expected.

**Doctor of Philosophy Degree Requirements**

The Ph.D. in biomedical engineering is offered in accordance with the general requirements for doctoral degrees as specified in the Requirements for Graduate Degree Section of this catalog. Specific program of study requirements include the following:

1. Completion of a minimum of 48 hours of graduate credits to include: a minimum of 24 credits of course work beyond the master’s degree and a minimum of 24 credits of dissertation research. At least 15 credits of non-dissertation course work must be at the 800-level.

2. Successful completion of a written diagnostic examination before the end of the first academic year.

3. Successful completion of a written and oral qualifying examination near the completion of the coursework.

4. Successful presentation of a dissertation research proposal at the beginning of the dissertation research.

5. The successful completion and public defense of a dissertation representing independent, original research worthy of publication in a peer-reviewed scholarly journal.

The program of study will be developed with the approval of the graduate program director and the student’s advisor. The program shall include a common core of 12 credits and 12 credits of technical electives.

**Common Core**

<table>
<thead>
<tr>
<th>Credit Hours</th>
<th>Course Name</th>
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<tr>
<td>12</td>
<td>BME 820</td>
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<tr>
<td>12</td>
<td>BME 821</td>
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<tr>
<td>12</td>
<td>BME 822</td>
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Biomedical Engineering Program
**BME Electives**

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<tr>
<th>Course</th>
<th>Title</th>
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<tbody>
<tr>
<td>BME 501</td>
<td>Biomedical Engineering I: Principles</td>
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<td>BME 554</td>
<td>Introduction to Bioelectricity</td>
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<td>BME 562</td>
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<td>BME 564</td>
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<tr>
<td>BME 895</td>
<td>Special Topics in Biomedical Engineering</td>
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</table>

Total Hours: 24

* Students who have completed any of the core courses at the 700-level as part of a previous degree or program may substitute these courses with 800-level BME electives approved by the graduate program director.

** The technical elective courses provide a basis for dissertation research and future career objectives. These courses can be selected from the biomedical engineering technical electives or a wide variety of appropriate graduate courses in engineering, biology, chemistry, psychology, computer science, modeling and simulation, mathematics, statistics, or other programs. No more than six credits from course work satisfying foundation knowledge requirements may be included in the program of study for elective credit. At least 15 credits of non-dissertation course work must be at the 800-level. A minimum of 3 credits must be selected from the biomedical engineering technical electives list; the remaining credits can be selected from this list or other graduate courses with approval of the student's advisor and the graduate program director.

### Advanced Engineering Certificate - Biomedical Engineering

The Graduate Certificate in Biomedical Engineering Program offers students and professionals the opportunity to further their knowledge with advanced study in the growing area of Biomedical Engineering. The program is designed to provide well-rounded instruction in several key facets of Biomedical Engineering. Those who complete the program receive the Advanced Engineering Certificate in Biomedical Engineering from Old Dominion University and a letter of recognition from the Batten College of Engineering and Technology. Courses taken for the certificate program may later be applied to the M.E. or Ph.D. degree in Biomedical Engineering. For complete information on the admission and certificate requirements, please refer to the Batten College of Engineering and Technology's section on graduate certificate programs at: [graduate/frankbattencollegeengineeringandtechnology/interdisciplinarygraduatecertificateprograms](http://catalog.odu.edu/graduate/frankbattencollegeengineeringandtechnology/interdisciplinarygraduatecertificateprograms).

### BIOMEDICAL ENGINEERING Courses

**BME 501. Biomedical Engineering I: Principles. 3 Credits.**
The course exposes students to principles used in biomedical engineering. The major focus is on physiology including cell, muscle, and the cardiovascular, respiratory, gastrointestinal and central nervous systems. Furthermore, there will be modules on biomechanics, biomaterials, biochemistry, tissue engineering and moral and ethical principles in biomedical engineering.

**BME 502. Biomedical Engineering II: Applications. 3 Credits.**
The course is a continuation of BME 401 and BME 501. This course exposes students to modern biomedical engineering applications aligned with the principles and physiological processes covered in the previous course. Selected topics include: prosthetic devices, tissue engineering applications, neural interfaces, cardiac devices and imaging techniques. Prerequisites: BME 401 or BME 501.

**BME 554. Introduction to Bioelectricity. 3 Credits.**
This course covers the electrical properties of cells and tissues as well as the use of electrical and magnetic signals and stimuli in the diagnosis and treatment of disease. Typical topics to be covered include basic cell physiology, endogenous electric fields in the body, electrocardiography, cardiac pacing defibrillation, electrotherapy, electroration, electrotherapy in wound healing. In addition ultra-short electrical pulses for intracellular manipulation and the application of plasmas to biological systems will be covered.

**BME 562. Introduction to Medical Image Analysis. 3 Credits.**
Introduction to basic concepts in medical image analysis. Medical image registration, segmentation, feature extraction, and classification are discussed. Basic psychophysics, fundamental ROC analysis and FROC methodologies are covered. Cross-listed with ECE 562/MSIM 562.

**BME 564. Biomedical Applications of Low Temperature Plasmas. 3 Credits.**
This course covers the electrical properties of cells and tissues as well as the use of electrical and magnetic signals and stimuli in the diagnosis and treatment of disease. Typical topics to be covered include basic cell physiology, endogenous electric fields in the body, electrocardiography, cardiac pacing defibrillation, electrotherapy, electroration, electrotherapy in wound healing. In addition ultra-short electrical pulses for intracellular manipulation and the application of plasmas to biological systems will be covered.

**BME 567. Advanced Biometrics. 3 Credits.**
A one-semester course covering advanced topics in bioelectricity. The course will cover advanced applications of pulsed power and plasma in the medical, biological and environmental fields. (Cross listed with ENGN 630.)

**BME 695. Topics in Biomedical Engineering. 3 Credits.**
This course will be offered as needed, depending upon the need to introduce special subjects to target specific areas of master’s level specializations in biomedical engineering.

**BME 699. Master’s Thesis. 1-9 Credits.**
Directed research for the master’s thesis. Prerequisite: departmental approval.

**BME 720. Modern Biomedical Instrumentation. 3 Credits.**
This course covers the design of modern biomedical instruments including select diagnostic, assistive, therapeutic, prosthetic, imaging, and virtual devices and systems. Techniques for mechanical, electrical, and chemical sensor and transducer design; stimulation and measurement; data acquisition; digital signal processing; and data visualization will be examined.

**BME 721. Mathematical Modeling in Physiology I. 3 Credits.**
The first of a two-course series covering human physiology and pathophysiology, with an emphasis on quantitative modeling, simulation, and analysis of the function of cells, organs, and systems. This course focuses on cellular physiology, including homeostasis, membrane ion channels, excitability, calcium dynamics, and intercellular communication.
BME 722. Mathematical Modeling in Physiology II. 3 Credits.
The second course of a two-course series covering human physiology and pathophysiology with an emphasis on quantitative modeling, simulation, and analysis of the function of cells, organs, and systems. This course focuses on systems physiology, including the heart, respiration, muscle, kidneys, and the endocrine system. Prerequisites: BME 721 or BME 821.

BME 724. Neural Engineering. 3 Credits.
This course presents engineering techniques for the restoration and augmentation of human function via direct interactions between the nervous system and artificial devices, with particular emphasis on brain-computer interfaces. Novel interfaces, hardware and computational issues, and practical and ethical considerations will also be covered.

BME 751. Computational and Statistical Methods in Biomedical Engineering. 3 Credits.
This course covers the theoretical foundation and application of commonly used techniques in biomedical engineering. Topics include linear algebra, partial differential equations, regression analysis, applied probabilities, multivariate distributions, Bayesian statistics, hypothesis tests, multiple comparisons, ANOVA, solution of non-linear equations, numerical methods and optimization. Programming software will be used to perform simulations and analyze biomedical data. Prerequisites: Graduate status.

BME 762. Applied Medical Image Analysis. 3 Credits.
Course explores hands-on exposure to state-of-the-art algorithms in medical image analysis, which builds on open-source software (Insight Segmentation and Registration Toolkit - ITK), as well as the principles of medical image acquisition in the modalities of clinical interest. Medical imaging modalities - X-rays, CT, and MR/ITK image pipeline; image enhancement, feature detection; segmentation - basic techniques, feature-based classification and clustering, graph cuts, active contour and surface models; surface and volume meshing; registration - transformations, similarity criteria; shape and appearance models are all explored and discussed in this course. Prerequisites: Knowledge of C++ and object-oriented programming.

BME 783. Digital Image Processing. 3 Credits.
Principles and techniques of two-dimensional processing of images. Concepts of scale and spatial frequency. Image filtering in spatial and transform domains. Applications include image enhancement and restoration, image compressing, biomedical imaging for diagnosis of disease, and image segmentation for computer vision. Prerequisites: ECE 782 or ECE 882.

BME 791. Biomedical Engineering Innovation Seminar. 1-3 Credits.
This course is for students interested in research that originates from a clinical need, is developed in the laboratory and is then implemented clinically. Seminars by healthcare professionals emphasize clinical needs. Students follow the biodesign innovation process toward creation of biotechnologies and devices that address needs.

BME 795. Special Topics in Biomedical Engineering. 1-3 Credits.
Special courses covering selected graduate-level topics in biomedical engineering.

BME 797. Independent Study. 1-3 Credits.
This course allows students to develop specialized expertise by independent study (supervised by a faculty member). Prerequisites: departmental approval.

BME 820. Modern Biomedical Instrumentation. 3 Credits.
This course covers the design of modern biomedical instruments including select diagnostic, assistive, therapeutic, prosthetic, imaging, and virtual devices and systems. Techniques for mechanical, electrical, and chemical sensor and transducer design; stimulation and measurement; data acquisition; digital signal processing; and data visualization will be examined.

BME 821. Mathematical Modeling in Physiology I. 3 Credits.
The first of a two-course series covering human physiology and pathophysiology, with an emphasis on quantitative modeling, simulation, and analysis of the function of cells, organs, and systems. This course focuses on cellular physiology, including homeostasis, membrane ion channels, excitability, calcium dynamics, and intercellular communication.

BME 822. Mathematical Modeling in Physiology II. 3 Credits.
The second course of a two-course series covering human physiology and pathophysiology with an emphasis on quantitative modeling, simulation, and analysis of the function of cells, organs, and systems. This course focuses on systems physiology, including the heart, respiration, muscle, kidneys, and the endocrine system. Prerequisites: BME 721 or BME 821.

BME 824. Neural Engineering. 3 Credits.
This course presents engineering techniques for the restoration and augmentation of human function via direct interactions between the nervous system and artificial devices, with particular emphasis on brain-computer interfaces. Novel interfaces, hardware and computational issues, and practical and ethical considerations will also be covered.

BME 851. Computational and Statistical Methods in Biomedical Engineering. 3 Credits.
This course covers the theoretical foundation and application of commonly used techniques in biomedical engineering. Topics include linear algebra, partial differential equations, regression analysis, applied probabilities, multivariate distributions, Bayesian statistics, hypothesis tests, multiple comparisons, ANOVA, solution of non-linear equations, numerical methods and optimization. Programming software will be used to perform simulations and analyze biomedical data. Prerequisites: Graduate status.

BME 862. Applied Medical Image Analysis. 3 Credits.
Course explores hands-on exposure to state-of-the-art algorithms in medical image analysis, which builds on open-source software (Insight Segmentation and Registration Toolkit - ITK), as well as the principles of medical image acquisition in the modalities of clinical interest. Medical imaging modalities - X-rays, CT, and MR/ITK image pipeline; image enhancement, feature detection; segmentation - basic techniques, feature-based classification and clustering, graph cuts, active contour and surface models; surface and volume meshing; registration - transformations, similarity criteria; shape and appearance models are all explored and discussed in this course. Prerequisites: Knowledge of C++ and object-oriented programming.

BME 883. Digital Image Processing. 3 Credits.
Principles and techniques of two-dimensional processing of images. Concepts of scale and spatial frequency. Image filtering in spatial and transform domains. Applications include image enhancement and restoration, image compressing, biomedical imaging for diagnosis of disease, and image segmentation for computer vision. Prerequisites: ECE 783 and ECE 883.

BME 891. Biomedical Engineering Innovation Seminar. 1-3 Credits.
This course is for students interested in research that originates from a clinical need, is developed in the laboratory and is then implemented clinically. Seminars by healthcare professionals emphasize clinical needs. Students follow the biodesign innovation process toward creation of biotechnologies and devices that address needs.

BME 895. Special Topics in Biomedical Engineering. 1-3 Credits.
Special courses covering selected graduate-level topics in biomedical engineering.

BME 897. Independent Study. 1-3 Credits.
This course allows students to develop specialized expertise by independent study (supervised by a faculty member). Prerequisites: departmental approval.

BME 899. PhD Dissertation Research. 1-9 Credits.
1-9 credits. Directed research for the doctoral dissertation.

BME 999. Doctoral Graduate Credit. 1 Credit.
This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.